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# TRACE ELEMENTS IN ILLINOIS PENNSYLVANIAN LIMESTONES

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ABSTRACT

The possibility that agricultural limestone might contain sufficient amounts of trace elements to benefit plants growing in soil to which it has been applied has aroused considerable interest and this investigation was made to determine the variety and amount of trace elements present in Illinois limestones.

Ninety-two limestone samples were taken from rock exposed in thirty-five quarries operating when the sampling was done. Shales associated with some of the limestones also were sampled. Spectrochemical analyses were made of the samples for 15 trace elements and elements occurring in minor amounts, including barium, boron, chromium, copper, iron, lead, manganese, molybdenum, nickel, potassium, sodium, strontium, titanium, vanadium and zinc.

The amounts of trace elements in the Pennsylvanian limestones vary greatly. The shales associated with some of the limestones contain a greater content of most trace elements than do the limestones. Those limestones containing clay or shale as an impurity are likely to contain a greater amount of trace elements than purer limestones, as are agricultural limestones produced from deposits including shale strata that are not eliminated during quarrying.

The average values for all limestone samples show the following abundance of elements: 0.1 percent or more - iron, potassium and manganese; less than 0.1 but 0.01 percent or more - barium, sodium, strontium, and titanium; less than 0.01 percent - boron, chromium, copper, molybdenum, nickel, lead, and zinc.

Similar data for the averages for all shale samples are: 0.1 percent or more - iron, potassium, sodium, and titanium; less than 0.1 percent but 0.01 percent or more - boron, barium, chromium, manganese, nickel, lead, strontium, and zinc; less than 0.01 percent - copper, molybdenum, and vanadium.

## INTRODUCTION

The Pennsylvanian limestones of Illinois are quarried at many places and supply a large tonnage of crushed stone sold for agricultural limestone and road material. This investigation was made in response to repeated requests for information regarding the trace element content of these limestones because of the possibility that the limestones might contain trace elements of suitable kind and amount to be beneficial to the growth of plants. Certain trace elements are known to be beneficial if applied to the soil in a suitable form and quantity. This report deals with the kinds and amounts of trace elements in the limestones, but questions relating to their availability and value to plants are not geological matters and therefore are beyond the scope of this study.

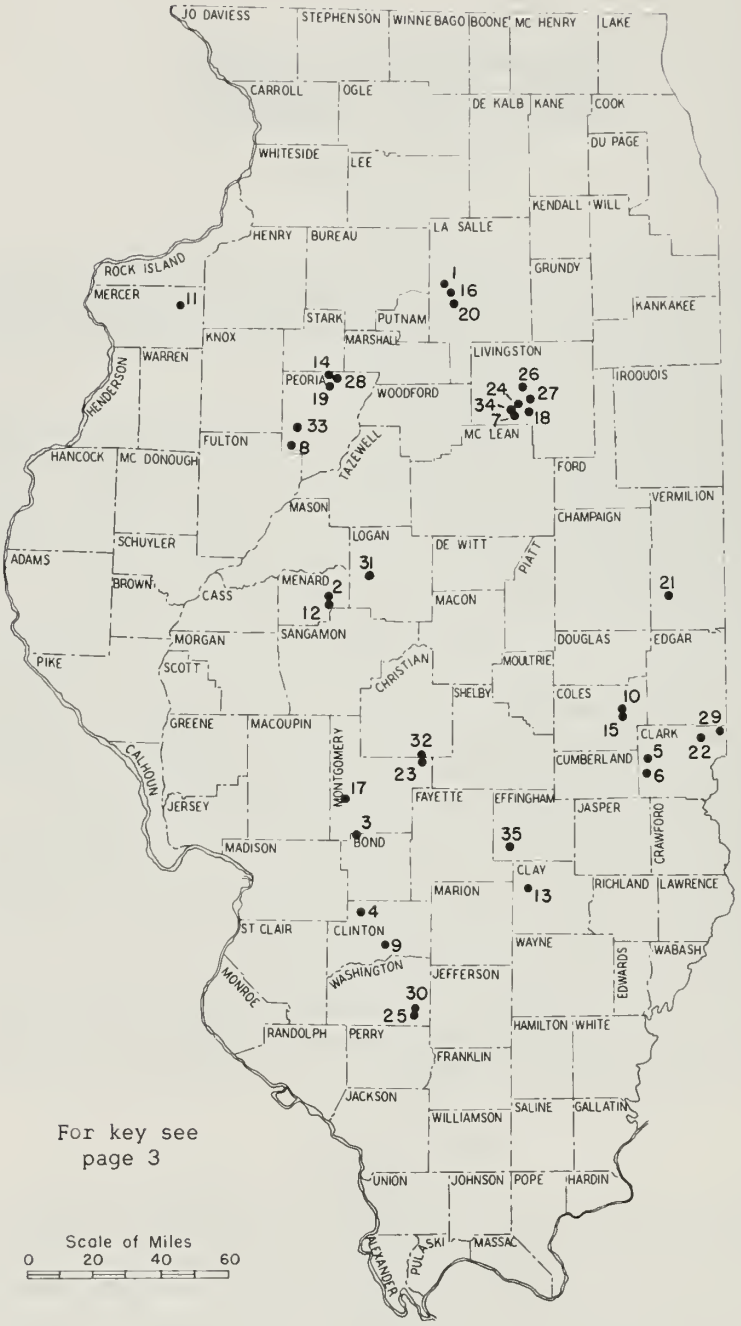



Fig. 1. - Locations and names of the quarries sampled, the geologic identity of the rock units being quarried, and the sample numbers.

## KEY TO INDEX MAP

| Map No. | Quarry | Limestone | Sample No. |
|---|---|---|---|
| 1 | Alpha Portland Cement Company | LaSalle | 235-242 |
| 2 | Athens Stone Quarry | Lonsdale | 228-233 |
| 3 | Bond Stone Company | Shoal Creek | 154-155 |
| 4 | Buehne Quarry Company | Shoal Creek | 138-142 |
| 5 | Casey Stone Company (north quarry) | Livingston | 122-129 |
| 6 | Casey Stone Company (south quarry) | Livingston | 114-116, 118-120 |
| 7 | Chenoa Stone Company | Pontiac | 190-191 |
| 8 | Chipman Stone Company | Lonsdale | 174-175 |
| 9 | Huelsman Quarry Company | Shoal Creek | 144-149 |
| 10 | Humphres Stone Quarry | Livingston | 217-218, 220-221 |
| 11 | Independent Materials Company | Seville | 177 |
| 12 | Indian Point Limestone Products Company | Lonsdale | 164-169 |
| 13 | Iola Stone and Materials Company | Omega | 202-204 |
| 14 | Lamar Stone Company | Lonsdale | 185-188 |
| 15 | Langs Stone Quarry | Livingston | 225-226 |
| 16 | Lehigh Portland Cement Company | LaSalle | 260 |
| 17 | Litchfield Stone Company | Shoal Creek | 152-153 |
| 18 | Livingston Stone Company | Pontiac | 199-200 |
| 19 | Long Rock Company | Lonsdale | 179-180 |
| 20 | Marquette Cement Manufacturing Company | LaSalle | 244-248 |
| 21 | Material Service Corporation | Livingston | 264 |
| 22 | Montgomery Stone Quarry | Livingston | 206-211 |
| 23 | Nokomis Limestone Quarry | Millersville | 106-112 |
| 24 | Ocoya Stone Company | Pontiac | 196-197 |
| 25 | Pitts Quarry Company, Inc. | Shoal Creek | 135 |
| 26 | Pontiac Stone Company | Pontiac | 101, 103 |
| 27 | Pontiac Stone Company (McDowell Quarry) | Pontiac | 104, 105 |
| 28 | Princeville Stone Company | Lonsdale | 182-183 |
| 29 | Quality Lime Company | Livingston | 213-214 |
| 30 | Radom Quarry | Shoal Creek | 132-133 |
| 31 | Rocky Ford Limestone Company | Lonsdale | 162-163 |
| 32 | Tri-County Stone Company | Millersville | 256 |
| 33 | Trivoli Stone Company | Lonsdale | 171-172 |
| 34 | Wagner Stone Company | Pontiac | 193-194 |
| 35 | Winters Stone Quarry | Omega | 158-159 |

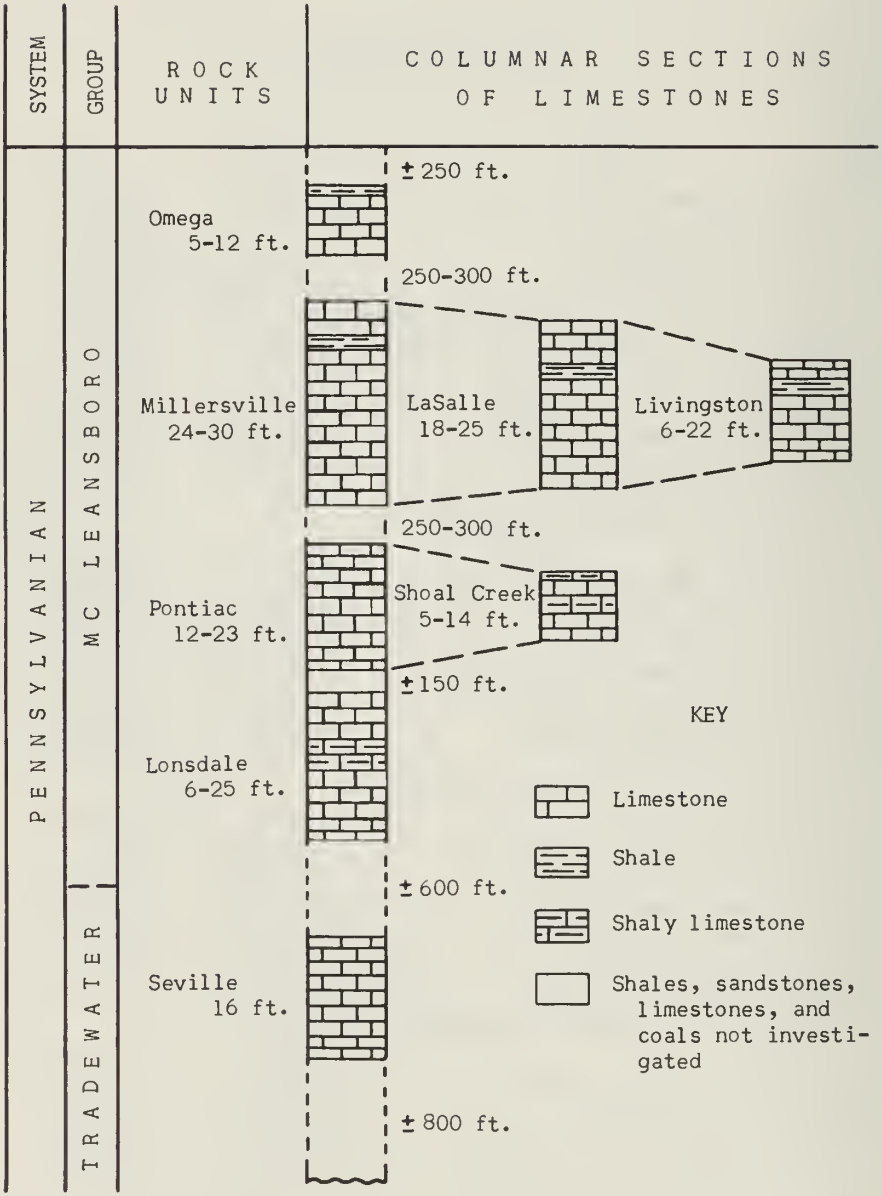



Fig. 2. - Generalized succession of limestones sampled, probable lateral relationships between limestones, and thickness variations of limestones as exposed in quarries sampled.

Samples were taken from recently exposed faces in all quarries known to be operating at the time the sampling was done. If the quarry faces included both limestone and shale, the materials were sampled separately. Tests were run on 92 limestone and 17 shale samples from 35 quarries in 17 counties. Data are not given on the trace element content of the agricultural limestone being produced when the sampling was done because of the uncertainty that any one such sample from a quarry would adequately represent the deposit being worked.

Trace elements found in the samples were boron, barium, chromium, copper, iron, potassium, manganese, molybdenum, sodium, nickel, lead, strontium, titanium, vanadium, and zinc. The amounts of iron, potassium, and sodium present in some of the samples are too great to be regarded as trace amounts but the data are given for completeness and for convenience the elements are listed as trace elements.

## ACKNOWLEDGMENTS

The analytical data in this report that were obtained by means of the A.C. arc were determined by Juanita Witters, those obtained by use of the D.C. arc were determined by Kozo Nagashima. J. E. Lamar and D. W. Hutcheson also contributed in various ways to the investigation. Their assistance is gratefully acknowledged.

## METHODS OF ANALYSIS

All spectrochemical data were obtained with a Bausch and Lomb large Littrow spectrograph. The excitation source was a National Spectrographic Laboratories Spec-Power. A National Spectrographic Laboratories Spec-Reader was used for measuring line densities.

Measurements for boron, barium, cobalt, chromium, copper, molybdenum, nickel, lead, strontium, and zinc were made relative to calcium by use of the A.C. arc. The shale samples and the samples of limestone that were low in calcium were diluted with purified calcium carbonate to provide mixtures at least 85 percent calcium carbonate.

Iron, potassium, sodium, manganese, and titanium were determined by means of direct current arc methods developed by Nagashima. For potassium, 100 parts by weight of the sample were mixed with 1 part RbCl (internal standard) and 99 parts by weight $Li_2CO_3$ (buffer). About 25 mg. of the mixture were arced to completion (10 amperes for 40 seconds).

For iron, manganese, sodium, and titanium, 1 part by weight sample was mixed with 5 parts by weight buffer-internal standard mixture of the following composition in parts by weight; 2 parts $Li_2CO_3$, 3 parts graphite, 0.0025 parts $In_2O_3$, and 0.0010 parts $Co_3O_4$. About 15 mg. of the sample plus buffer-internal standard mixture was arced to completion at 10 amperes for 90 seconds.

## SUCCESSION AND CHARACTER OF LIMESTONE STRATA

The names and locations of the quarries sampled, the geological formation being quarried, and the identifying numbers of the samples taken are shown in figure 1 and the accompanying key. The succession of limestones sampled is given in figure 2.

The limestones range from 5 to 30 feet thick and average about 15 feet thick. The thinnest limestones are the Omega and Shoal Creek. The thickest

limestone is the Millersville, which is about 30 feet thick in a quarry in Montgomery County; the LaSalle and Lonsdale limestones also approach this thickness. Local variations in the thickness may be attributed, at least in part, to erosion.

All the limestones, except the LaSalle and Seville, are used as sources of agricultural limestone and all furnish road material except the LaSalle. The LaSalle limestone is currently being used only as a source of material for making Portland cement, but it formerly was used as a source of agricultural limestone. The Seville limestone is being quarried only near Viola, Mercer County, and is used as road material.

Many of the limestones sampled during this investigation vary vertically in purity, texture, or other characteristics. Some of them consist of an upper unit of one kind of limestone and a lower unit of another type. The LaSalle limestone comprises three such units in places. The terms "bench" and "benches" are used to refer conveniently to these limestone units of similar character. When so used, they do not refer to the benches or benching operations involved in quarrying.

The limestones investigated are all a part of the McLeansboro group of rocks in the upper part of the Pennsylvanian system, except the Seville limestone, which is a part of the Tradewater group in the lower part of the Pennsylvanian system.

### Omega Limestone

The Omega limestone is light gray, fine- to medium-grained, slightly clayey, and from 5 to 12 feet thick, with beds about 1 foot thick. It is quarried at two locations, one in Clay and one in Effingham County.

### Millersville, LaSalle, and Livingston Limestones

The Millersville, LaSalle, and Livingston limestones are believed to be equivalent to one another (Wanless and Siever, 1956, p. 7) and are roughly similar in lithologic character. They occur approximately 250 to 300 feet below the Omega limestone.

The Millersville limestone is quarried at two places, one in Christian County and the other in Montgomery County. These quarries are less than 500 yards apart and the stone displays only minor variations. There are two benches of limestone. The lower unit is about 15 feet thick in beds from 6 to 18 inches thick, gray mottled with dark gray, fine-grained, and contains small cavities lined with crystals of the mineral calcite. The upper unit is about 11 feet thick with beds 1 to 10 inches thick, is light brown to gray and contains a shaly limestone bed 5 feet below the top that is about 14 inches thick.

The LaSalle limestone is quarried at three places in LaSalle County. Most commonly it consists of two benches. The upper unit is light gray to brownish gray, contains medium- and coarse-grained fossil fragments, and is about 8 feet thick in beds from 1 inch to 3 feet thick. It is separated from the lower bench by a shaly limestone parting that may be up to 1 foot thick. The lower unit is light gray streaked and mottled with dark gray, fine- to medium-grained and clayey, contains small cavities lined with calcite, and is about 15 feet thick with beds 6 to 18 inches thick. At one place the lower 3 feet of this unit is separated laterally from the rest of the stone for a short distance by a 1-foot bed of shaly limestone. The shaly bed and the limestone below it are considered an unusual development and the analytical data regarding them are not used in subsequent discussions of the trace element characteristics of the lower bench.

In Vermilion, Clark, and Coles counties there are seven quarries operating in the Livingston limestone. The limestone is variable in character. It ranges in thickness from 6 to 21 feet with beds from 1 to 18 inches thick, and may comprise one or two benches. Where the limestone is about 6 feet thick, it is commonly all of the same character. Where it is about 9 feet thick, it is generally overlain by a foot of very shaly, greenish gray limestone. Thicker deposits may consist of a single unit as much as 19 feet thick, or of two benches that may total as much as 21 feet thick.

Where the Livingston limestone is a single thick unit, it is light gray mottled with dark gray, and contains cavities filled with calcite. Commonly it has a prominent parting or bedding plane about eight feet from the top. In some places calcareous shale up to 3 inches thick occurs at this horizon.

The thick double-unit Livingston is similar to the Millersville. The upper unit is about 6 feet thick, grayish brown, fine-grained, and contains thin calcite veinlets. It is separated from the lower bench by a 1-foot, noncalcareous, gray, shale parting. The lower bench is about 12 feet thick and is light gray mottled with dark gray, fine-grained, and contains calcite-filled cavities.

### Pontiac and Shoal Creek Limestones

The Pontiac and Shoal Creek limestones occur from 100 to 250 feet below the limestone just mentioned and are considered equivalent to one another (Weller et al., 1945). Six quarries are operating in the Pontiac limestone, all of them in Livingston County. The limestone ranges in thickness from 12 to 23 feet with beds from 1 to 12 inches thick. It is generally light gray mottled with dark gray and has occasional thin, shaly partings. It is fine- to medium-grained and contains numerous cavities filled with calcite crystals.

Farther to the south, in Bond, Clinton, Montgomery, and Washington counties, from 5 to 13 feet of Shoal Creek limestone is being quarried at six places. In four of the quarries the limestone is a single unit and is light gray to gray with scattered horizontal black streaks. It is commonly fine- to medium-grained, and massive. The Shoal Creek generally is composed of 1- to 14-inch beds. In two of the quarries the limestone is between 6 and 8 feet thick and is divided into two benches by a parting of greenish shale 6 to 12 inches thick. However, both benches of limestone are similar and are light gray with dark gray streaks, and fine-grained.

### Lonsdale Limestone

The Lonsdale limestone lies approximately 150 to 200 feet below the Shoal Creek and Pontiac limestones. Eight quarries are operating in the limestone in Logan, Menard, and Peoria counties. The limestone ranges from 6 to 26 feet thick, with beds from 1 to 24 inches thick. The formation may consist of a single bench or of two benches separated by about one foot of shale. Where it is a single bench, the limestone generally is light gray mottled dark gray and slightly clayey. Where there are two benches the lithology of the lower unit closely resembles that of the single bench and commonly is light gray mottled with dark gray, and fine- to medium-grained. The upper unit generally is brownish gray or light gray with dark gray streaks, and is slightly coarser grained than the lower bench.

### Seville Limestone

Sixteen feet of Seville limestone is quarried in Mercer County. This limestone occurs from 400 to 600 feet below the Lonsdale and is light brown to dark gray, fine-grained, very argillaceous, siliceous, hard, and brittle. The Seville limestone sample is less pure than the other samples tested. It is crushed primarily for road material.

## SAMPLING AND PREPARATION OF SAMPLES

The samples used in this investigation were taken from active or recently operated quarry faces and thus represent fresh unweathered rock. Where it was possible to sample a quarry face at two well separated sites, this was done to obtain information on lateral variation (Lamar and Thomson, 1956, p. 17).

In sampling, "quarry samples" consisting of pieces of stone about 6 inches in diameter, were taken at 1-foot vertical intervals at each sampling site. If several types of rock occurred in the quarry face, each type was sampled separately. Thus, if a deposit consisted of 2 benches of limestone separated by a bed of shale, the pieces of stone from the upper limestone bench composed a single sample as did the pieces of the lower limestone and the pieces of the shale.

In the laboratory, shale samples were prepared for analysis by splitting out interior portions of the quarry samples and pulverizing them in a ball mill. The quarry samples of limestone were first washed with distilled water to remove adhering dust or dirt and then allowed to dry. Each was then split mechanically and a piece of stone obtained that had had no contact with metal. Equal amounts of each of these pieces were combined to make the final laboratory sample for analysis. The laboratory sample was crushed in a hard-steel-faced crusher and then ground in a ball mill for two hours to a very fine powder.

## SIGNIFICANCE OF SAMPLES

The data given herewith on the trace-element content of the samples tested are regarded as indicative only of the composition of the material sampled at the places where the samples were taken. Many more samples would be required to establish an average figure for the stone in a quarry or the agricultural limestone produced from it (Lamar and Thomson, 1956). The limestone sampled has no doubt been quarried away since the samples were taken. However, the data obtained from them still have value.

The chief value of the data on samples is that it gives (1) a general idea of the expectable kinds and amounts, or range of amounts, of trace elements in the limestones and shale beds, (2) information on the variability of composition within quarries, and (3) a basis for evaluating the contribution of shale or clays in the limestone deposits to trace-element content.

## DEPOSITS SAMPLED

A brief description of the deposits sampled follows. In the event that a quarry was sampled at two places, description of the stone exposed at each place is given if the two sites differed importantly. Quarries are listed in alphabetical order and sample numbers are indicated. The name of the geologic formation being quarried follows the company name. Reference numbers pertaining to general geographic locations shown in figure 1 precede company names.

1. Alpha Portland Cement Company, LaSalle limestone, NE¼ NE¼ SE¼ sec. 14 T. 33 N., R. 1 E., LaSalle County.

| | Thickness Ft. | In. |
|---|---|---|
| Overburden: glacial till and loess. | | |
| Limestone, light brownish gray, fine-grained, beds 1 to 5 inches thick, upper 8 inches more coarse-grained. Sample 235. | 7 | |
| Limestone, light greenish gray, shaly, contains abundant very fossiliferous nodules. Sample 236. | 1 | 6 |
| Limestone, light gray, medium-grained, beds 6 to 15 inches thick. Sample 237. | 13 | |
| Other samples were collected 400 yards to the north and description follows. | | |
| Limestone: upper 2 feet light brownish gray, very fine-grained, with a little chert; middle foot gray to greenish gray, very clayey and nodular; and lower 3 feet light gray, medium-grained, beds 3 to 14 inches. Samples 238-240, combined in 1 sample. | 6 | |
| Limestone, light gray to grayish green, very shaly, nodular, and very fossiliferous. Sample 241. | 1 | |
| Limestone, light gray, fine- to medium-grained, becoming finer grained and more clayey toward base, some oil, pyrite, and barite 2 to 3 feet from top in porous zone. Sample 242. | 11 | |
| Covered. | 6 | |
| Shale, black. | 1+ | |

2. Athens Stone Quarry, Lonsdale limestone, NE¼ NE¼ NW¼ sec. 19, T. 18 N., R. 5 W., Menard County.

| | | |
|---|---|---|
| Overburden: glacial till and loess. | | |
| Limestone, light gray horizontally streaked with dark gray, fine-grained, beds 1 to 8 inches thick, top 7 inches coarse-grained; some cavities filled with crystalline calcite. Sample 228. | 9 | |
| Shale, black at top grading down to light grayish green at base, poorly bedded. Sample 229. | 1 | 6 |
| Limestone, light gray mottled with dark gray, fine-grained, beds 2 to 18 inches thick, some cavities filled with crystalline calcite. Sample 230. | 15 | |
| Shale, black, fairly well bedded. | 1+ | |
| Other samples of similar description, but with the thicknesses indicated below, were collected 100 yards to the east. | | |
| Limestone, clayey. Sample 231. | 7 | |
| Shale. Sample 232. | 1 | 6 |
| Limestone. Sample 233. | 12 | |
| Shale, black. | 1+ | |

3. Bond Stone Company, Shoal Creek limestone, W½ SW¼ NW¼ sec. 29, T. 7 N., R. 4 W., Bond County.

| | Thickness Ft. | In. |
|---|---|---|
| Overburden: till and loess. | | |
| Limestone, light gray horizontally streaked with dark gray, fine-grained, clayey, beds 4 to 10 inches thick. Sample 154. | 12 | |
| Limestone; not excavated. | 2 | |
| Shale. | 1 | |

Another sample of similar description and thickness was collected 60 yards to the east. Sample 155.

4. Buehne Quarry Company, Shoal Creek limestone, SW¼ SW¼ SE¼ sec. 22, T. 3 N., R. 4 W., Clinton County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Shale, gray to dark gray, nodular in upper 6 feet. | 8 | |
| Limestone, light gray, fine-grained. Sample 138. | 3 | |
| Shale parting; sample not accessible. | | 6± |
| Limestone, same as Sample 138. Sample 139. | 3 | |

Other samples of each of the units described above were collected 50 yards to the southeast.

| | | |
|---|---|---|
| Limestone. Sample 142. | 3 | |
| Shale. Sample 140. | 1 | |
| Limestone. Sample 141. | 3 | |

5. Casey Stone Company, North Quarry, Livingston limestone, SW¼ SE¼ SW¼ sec. 28, T. 10 N., R. 14 W., Clark County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, brown and gray, fine-grained, locally mottled dark gray. Sample 124. | 5 | 6 |
| Shale, gray, noncalcareous. Sample 125. | | 7 |
| Limestone, light gray mottled dark gray, fine- to medium-grained. Sample 126 (collected 75 yards southwest of samples 124 and 125). | 12 | |

Other samples of each unit described above, but with the thicknesses indicated below, were collected.

200 yards southeast of sample 126.

| | | |
|---|---|---|
| Limestone. Sample 127. | 5 | 6 |
| Shale. Sample 128. | | 8 |
| Limestone. Sample 129 (collected 50 yards southwest of samples 127 and 128). | 12 | |

150 yards east-southeast of sample 126.

| | | |
|---|---|---|
| Limestone. Sample 122. | 5 | |
| Shale. Sample 123. | 1 | 4 |
| Limestone; no sample. | | |

6. Casey Stone Company, South Quarry, Livingston limestone, SW¼ SE¼ SE¼ sec. 4, T. 19 N., R. 14 W., Clark County.

| | Thickness Ft. | In. |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone: top 6 inches gray, medium- to coarse-grained and fossiliferous; bottom 6 feet pinkish brown, fine-grained, with veinlets of calcite. Sample 114. | 6 | 6 |
| Shale, gray, noncalcareous. Sample 115. | 1 | 3 |
| Limestone, gray mottled with tan, fine-grained, beds 4 inches to 3 feet thick, with small cavities filled with crystalline calcite. Sample 116 (collected 50 yards west of samples 114 and 115). | 12 | 6 |

Other samples of each unit described above, but with the thicknesses indicated below, were collected.

| | | |
|---|---|---|
| Limestone. Sample 119 (500 feet northwest of samples 114 and 115). | 6 | |
| Shale. Sample 120 (500 feet northwest of samples 114 and 115). | 1 | |
| Limestone. Sample 118 (475 feet north of samples 114 and 115). | 14 | |

7. Chenoa Stone Company, Pontiac limestone, SE¼ SE¼ SW¼ sec. 19, T. 27 N., R. 5 E., Livingston County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray mottled with dark gray, fine-grained, beds 1 to 3 inches thick in upper 2 feet grading down to 3 to 8 inches thick in lower 13 feet, numerous small cavities filled with crystalline calcite. Sample 190. | 15 | |

Another sample of similar description, but 19 feet thick, was collected 200 yards to the south-southeast. Sample 191.

8. Chipman Stone Company, Lonsdale limestone, NW¼ NW¼ SW¼ sec. 28, T. 8 N., R. 5 E., Peoria County.

| | | |
|---|---|---|
| Overburden: glacial till and loess. | | |
| Limestone, light gray mottled with dark gray, fine- to medium-grained, some small cavities filled with crystalline calcite, bottom 1 foot very shaly and soft. Sample 174. | 7 | |
| Shale, light gray, poorly bedded. | 1+ | |

Another sample of similar description, but only 6 feet thick, was collected 100 yards to the south-southeast. Sample 175.

9. Huelsman Quarry Company, Shoal Creek limestone, NW¼ SE¼ NW¼ sec. 36, T. 2 N., R. 3 W., Clinton County.

| | | |
|---|---|---|
| Overburden: glacial till and loess. | | |
| Limestone, light greenish gray, medium-grained, very clayey. Sample 144. | | 6± |
| Shale, greenish gray, poorly bedded. Sample 145. | | 6± |
| Limestone, light gray, locally horizontally streaked dark gray, fine-grained, beds 3 to 14 inches thick. Sample 146. | 7 | |

| | Thickness Ft. | In. |
|---|---|---|
| Other samples of each unit described above, but with the thicknesses indicated below, were collected about 600 yards north. | | |
| Limestone. Sample 147. | 1± | |
| Shale. Sample 148. | | 6± |
| Limestone. Sample 149. | 6 | |

10. Humphres Stone Quarry, Livingston limestone, SW¼ NE¼ SW¼ sec. 32, T. 13 N., R. 10 E., Coles County.

| | | |
|---|---|---|
| Overburden: glacial till and outwash. | | |
| Shale, light greenish gray, poorly bedded. | 1 | |
| Limestone, light gray to greenish gray, fine-grained, very shaly, slightly nodular. Sample 217. | 1 | |
| Limestone, light gray, fine-grained, beds 2 to 24 inches thick, numerous small cavities filled with crystalline calcite. Sample 218. | 9 | |
| Other samples of similar description, but with the thicknesses indicated below, were collected 60 yards to the southeast. | | |
| Shale. | | 6 |
| Limestone. Sample 220. | 2 | |
| Limestone. Sample 221. | 8 | |

11. Independent Materials Company, Seville limestone, W½ NE¼ NW¼ sec. 3, T. 14 N., R. 2 W., Mercer County.

| | | |
|---|---|---|
| Overburden: loess. | | |
| Limestone, very shaly and silty, light brown along weathered bedding planes grading to dark gray where rock is unweathered, fine-grained, hard, beds 1 to 18 inches thick. Sample 177. | 16 | |
| Shale, black | 1± | |

12. Indian Point Limestone Products Company, Lonsdale limestone, NW¼ SW¼ NE¼ sec. 19, T. 18 N., R. 5 W., Menard County.

| | | |
|---|---|---|
| Overburden: glacial till and loess. | | |
| Limestone, brown to gray with occasional horizontal dark gray streaks, fine-grained, scattered small cavities filled with crystalline calcite. Sample 169. | 7 | |
| Shale, greenish gray, moderately well bedded. Sample 167. | 1 | |
| Limestone, light gray mottled with dark gray, fine-grained, beds 6 to 24 inches thick, some small cavities filled with crystalline calcite. Sample 164 (collected 30 yards east of samples 167 and 169). | 10 | |
| Other samples of similar description, but different thicknesses, were collected. | | |

| | Thickness Ft. | In. |
|---|---|---|
| Limestone. Sample 168 (collected about 120 yards east-southeast of samples 167 and 169). | 7 | |
| Shale. Sample 166 (collected 80 yards east of samples 167 and 169). | 1 | |
| Limestone. Sample 165 (collected 60 yards south of samples 167 and 169). | 9 | |

13. Iola Stone and Materials Company, Omega limestone, NW¼ NW¼ SE¼ sec. 11, T. 4 N., R. 5 E., Clay County.

| | | |
|---|---|---|
| Overburden: soil and loess. | | |
| Shale, light gray, fairly well bedded. | 11 | |
| Shale, slightly calcareous, dark gray to black, fossiliferous, fairly well bedded. | | 6 |
| Limestone, light gray horizontally streaked with darker gray, fine- to medium-grained, beds 4 to 18 inches thick, clayey. Sample 202. | 12 | |

Another sample similar in character to sample 202 was collected 100 yards to the southwest. Sample 203.

14. Lamar Stone Company, Lonsdale limestone, NE¼ NE¼ SE¼ sec. 5, T. 11 N., R. 7 E., Peoria County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray mottled with darker gray, fine-grained, beds 1 to 12 inches thick, nodular, some small cavities filled with crystalline calcite. Upper 4 feet light brownish gray and shaly. Sample 185. | 23 | |

Other samples, descriptions of which are given below, were collected 400 yards to the east.

| | | |
|---|---|---|
| Limestone, light brownish gray, coarse-grained in upper 10 inches grading down to fine-grained, beds 1 to 3 inches thick. Sample 186. | 2 | |
| Calcareous shale, greenish gray, containing numerous limestone concretions up to ½ inch in diameter. Sample 187. | 1 | |
| Limestone, light gray mottled with dark gray, fine-grained, beds 1 to 8 inches thick separated by undulating shale partings. Sample 188. | 12 | |

15. Langs Stone Quarry, Livingston limestone, center SE¼ sec. 5, T. 12 N., R. 10 E., Coles County.

| | | |
|---|---|---|
| Overburden: glacial till and outwash. | | |
| Shale, light greenish gray, poorly bedded, locally with nodules of calcareous ironstone in upper 1 foot; grades down to shale, light gray, numerous calcareous nodules, some of which contain small cavities filled with crystalline calcite. | 6 | |

| | Thickness Ft. | In. |
|---|---|---|
| Limestone, light gray, fine-grained, beds 2 to 14 inches thick, numerous small cavities filled with crystalline calcite. Sample 225. | 6 | |
| Another sample of similar character was collected 20 yards to the east. Sample 226. | | |

16. Lehigh Portland Cement Company, LaSalle limestone, SW¼ SE¼ SW¼ sec. 24, T. 33 N., R. 1 E., LaSalle County.

| | | |
|---|---|---|
| Overburden: glacial till and loess. | | |
| Shale, gray, calcareous, well bedded. | 3 | |
| Shale, black, fairly well bedded. | 5 | |
| Shale, greenish gray, nodular, very calcareous. | 1 | |
| Shale, grayish green with irregularly shaped reddish stains, noncalcareous. | 10 | |
| Limestone: upper 1 foot pink, very coarse; next 6 feet pinkish brown, coarse-grained, beds 1 to 6 inches thick, numerous shaly partings, shaly zone near bottom may be from 1 to 3 feet thick; lower 10 feet, light to dark gray mottled with darker gray, fine- to medium-grained, bed 6 to 18 inches thick. Sample 260. | 17 | |

17. Litchfield Stone Company, Shoal Creek limestone, SW¼ NE¼ SW¼ sec. 2, T. 8 N., R. 5 W., Montgomery County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray to light reddish brown, with some small cavities filled with crystalline calcite, beds 1 to 3 inches thick in upper 4 feet grading down to 2 to 8 inches thick in bottom 9 feet. Irregular undulating shale partings in upper 4 feet. Sample 152. | 13 | |
| Another sample of similar description and thickness was collected 70 yards to the east. Sample 153. | | |

18. Livingston Stone Company, Pontiac limestone, NW¼ SW¼ NW¼ sec. 23, T. 27 N., R. 5 E., Livingston County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray mottled with dark gray, fine-grained beds 1 to 8 inches thick, shale partings more numerous at top and thicker at base. Sample 199. | 13 | |
| Another sample of similar description was collected 400 yards to the southeast. Sample 200. | | |

19. Long Rock Company, Lonsdale limestone, near cen. S. line, sec. 5, T. 11 N., R. 7 E., Peoria County.

| | Thickness Ft. | In. |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray mottled with dark gray, fine-grained, locally with very fine-grained silty layers, beds 1 to 8 inches thick and nodular with irregular shaly partings, very shaly. Sample 179. | 22 | |

Another sample similar in description, but 21 feet thick, was collected 80 yards to the southeast. Sample 180.

20. Marquette Cement Manufacturing Company, LaSalle limestone, NW¼ NW¼ SE¼ sec. 6, T. 33 N., R. 2 E., LaSalle County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Shale, grayish green with irregular reddish bands from 1 to 10 inches thick; several thin 1- to 4-inch discontinuous limestone beds 7 feet from base. | 10+ | |
| Limestone, light gray to brownish gray, coarse-grained in upper 4 feet grading down to medium- to fine-grained, beds 3 inches to 3 feet thick. Sample 244. | 8 | |
| Shale, light greenish gray, very calcareous, with limestone nodules. Sample 245. | | 10 |
| Limestone, light gray horizontally streaked and mottled with dark gray, fine- to medium-grained, some small cavities filled with crystalline calcite. Sample 246. | 12 | |
| Shale, medium to dark gray, slightly calcareous. Sample 247. | | 10 |
| Limestone, same as sample 246 but slightly more clayey. Sample 248. | 3+ | |
| Covered. | 2 | |
| Shale, black. | 1 | |

21. Materials Service Corporation, Livingston limestone, cen. S. line, SW¼ sec. 21, T. 18 N., R. 13 W., Vermilion County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, medium to dark gray, fine-grained with scattered irregular masses of crystalline calcite. Sample 264. | 18 | |

22. Montgomery Stone Quarry, Livingston limestone, cen. SE¼ sec. 7, T.11 N., R. 11 W., Clark County.

| | | |
|---|---|---|
| Overburden: glacial till and outwash. | | |
| Limestone, reddish brown, medium-grained, massive. Sample 206. | 3 | |
| Shale, light gray to black. Sample 207. | 1 | |
| Limestone, light gray mottled with dark gray, fine- to medium-grained, beds 5 to 14 inches thick. Sample 208. | 12 | |

| | Thickness Ft. | In. |
|---|---|---|
| Other samples of similar description, but with the thicknesses indicated below, were collected 50 yards to the south-southeast. | | |
| Limestone. Sample 209. | 2 | |
| Shale. Sample 210. | 2 | |
| Limestone. Sample 211. | 9 | |

23. Nokomis Limestone Quarry, Millersville limestone, NE¼ NE¼ NE¼ sec. 3, T. 10 N., R. 2 W., Montgomery County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light brown to gray near top grading down to light gray near base, medium-grained, beds 1 to 10 inches thick. Sample 109. | 10 | 6 |
| An 18-inch bed of shale, green to gray and moderately well bedded, occurs 5 feet from the top of this limestone unit and was sampled separately. Sample 110. | | |
| Limestone, light gray mottled with dark gray, fine-grained, beds 6 to 18 inches thick containing some small cavities filled with crystalline calcite. Sample 106 (collected 100 feet southwest of samples 109 and 110). | 11 | |
| Other face samples of each unit described above, but with the thicknesses indicated below, were collected. | | |
| Limestone (sample 111). 10-inch shale bed 6 feet from top was sampled separately (sample 112). These two samples were collected 100 feet southeast of samples 109 and 110. | 11 | 10 |
| Limestone. Sample 107 (collected 200 feet southeast of sample 106). | 17 | |
| Limestone, dark gray, earthy (quarry floor). | 1 | 6 |

24. Ocoya Stone Company, Pontiac limestone, NW¼ NE¼ NE¼ sec. 19, T. 27 N., R. 5 E., Livingston County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray occasionally mottled with darker gray, fine-grained, beds 1 to 8 inches thick, numerous small cavities filled with crystalline calcite. Sample 196. | 13 | |
| Another sample of similar description was collected 100 yards to the northwest. Sample 197. | | |

25. Pitts Quarry Company, Inc., Shoal Creek limestone, SW¼ NE¼ NW¼ sec. 21, T. 3 S., R. 1 W., Washington County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Shale, gray, well bedded. | 4 | |

| | Thickness Ft. | In. |
|---|---|---|
| Limestone, gray horizontally streaked dark gray, fine-grained, with numerous thin shaly partings in the lower 4 feet. Sample 135. | 6 | |

26. Pontiac Stone Company, Pontiac limestone, SW¼ NE¼ SE¼ sec. 9, T. 28 N., R. 5 E., Livingston County.

| | | |
|---|---|---|
| Overburden: soil and sand. | | |
| Limestone, light gray to brown, medium-grained, beds 8 to 12 inches thick at base, grading to 1-inch beds near top. Scattered thin shale partings. Sample 101. | 16 | |
| Limestone, light gray to brown, beds 8 to 12 inches thick, clayey with thin shale partings. | 2+ | |

Another face sample of similar description, but only 12 feet thick, with a thin, medium- to coarse-grained bed 1 foot from the top, was collected 300 yards west of sample 101. Sample 103.

27. Pontiac Stone Company, McDowell Quarry, Pontiac limestone, SE¼ SW¼ NE¼ sec. 1, T. 27 N., R. 5 E., Livingston County.

| | | |
|---|---|---|
| Overburden: soil and glacial till. | | |
| Limestone, fine- to medium-grained, brown and thinly bedded in upper 5 feet, gray to light gray with beds 2 to 8 inches thick in underlying 9 feet, and gray and clayey in bottom 1 foot. Sample 104. | 15+ | |

Another face sample, with the description given below, was taken 500 feet northwest of sample 104.

| | | |
|---|---|---|
| Overburden: soil, sand, and clay. | | |
| Limestone, gray mottled with brown, fine- to medium-grained, beds ½ to 4 inches thick in upper 12 feet. Sample 105. | 12 | 6 |
| Covered. | 1 | 6 |
| Limestone, bluish gray, clayey. | | 6 |

28. Princeville Stone Company, Lonsdale limestone, NW¼ NW¼ SW¼ sec. 4, T. 11 N., R. 7 E., Peoria County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray locally mottled with dark gray, fine-grained, beds 1 to 14 inches thick, nodular, silty and clayey with scattered small cavities filled with crystalline calcite. Sample 182. | 25 | |

Another sample of similar description and thickness was collected 200 yards to the southwest. Sample 183.

29. Quality Lime Company, Livingston limestone, NW¼ SE¼ NW¼ sec. 29, T. 12 N., R. 10 W., Clark County.

| | Thickness Ft. | In. |
|---|---|---|
| Overburden: glacial till and outwash. | | |
| Limestone, light gray mottled with dark gray, very fine- to medium-grained beds 4 to 18 inches thick, some small cavities filled with crystalline calcite, a slightly nodular and clayey zone occurs between 2 and 5 feet from the top and a distinct parting, which may contain up to 3 inches of shale, occurs 8 feet from the top. Sample 213. | 21 | |
| Another sample, with the description given below, was collected 150 yards to the north-northeast. | | |
| Limestone, light gray mottled with dark gray, very fine- to medium-grained, beds 4 to 18 inches thick, some small cavities filled with crystalline calcite, prominent parting 8 feet from top containing no shale. Sample 214. | 19 | |

30. Radom Quarry, Shoal Creek limestone, cen. W. line, NW¼ SE¼ sec. 9, T. 3 S., R. 1 W., Washington County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Shale, gray, poorly bedded. | 7 | |
| Limestone, light gray horizontally streaked dark gray, fine-grained. Sample 132. | 7 | |
| Another sample of similar description, but only 5 feet thick, was collected 70 yards to the southeast. Sample 133. | | |

31. Rocky Ford Limestone Company, Lonsdale limestone, cen. of NE¼ sec. 7, T. 19 N., R. 3 W., Logan County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray, fine- to medium-grained beds 2 to 10 inches thick, with scattered small cavities filled with crystalline calcite. Sample 162. | 10 | |
| Shale, dark gray, well bedded, fossiliferous. | 1± | |
| Another sample of similar description, but only 9 feet thick, was collected 70 yards to the southwest. Sample 163. | | |

32. Tri-County Stone Company, Millersville limestone, SE¼ SE¼ SE¼ sec. 34, T. 11 N., R. 2 W., Christian County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light brownish gray, medium- to coarse-grained beds 1 to 8 inches thick, numerous small cavities and veinlets filled with crystalline calcite. Sample 256. | 7 | |
| Shale, light greenish gray, calcareous. | 0-3 | |
| Limestone not excavated. | 18± | |

33. Trivoli Stone Company, Lonsdale limestone, SW¼ SW¼ NW¼ sec. 35, T. 9 N., R. 5 E., Peoria County.

| | Thickness Ft. | In. |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray locally mottled with dark gray, fine-grained, some small cavities filled with crystalline calcite, beds ½ to 5 inches thick, very clayey. Sample 171. | 13 | |
| Limestone, gray, fine-grained, irregular bedding. Sample 172. | 6 | |

34. Wagner Stone Company, Pontiac limestone, NE¼ SE¼ NW¼ sec. 19, T. 27 N., R. 5 E., Livingston County.

| | | |
|---|---|---|
| Overburden: glacial till. | | |
| Limestone, light gray mottled with dark gray, fine-grained, beds 1 to 10 inches thick, scattered small cavities filled with crystalline calcite. Sample 193. | 23 | |
| Shale, dark gray, well bedded. | 1+ | |

Another sample, with the description given below, was collected 400 yards to the south-southeast.

| | | |
|---|---|---|
| Limestone, light brownish gray in the upper 4 feet grading down to light gray mottled with dark gray in lower 17 feet, fine-grained except for a 6-inch coarse-grained zone at the top, beds 3 to 12 inches thick; a 6-inch shaly zone occurs 4 feet from the top, below which occur numerous small cavities filled with crystalline calcite. Sample 194. | 22 | |

35. Winters Stone Quarry, Omega limestone, NW¼ NE¼ NE¼ sec. 13, T. 6 N., R. 4 E., Effingham County.

| | | |
|---|---|---|
| Overburden: soil and loess. | | |
| Limestone, light gray, fine-grained, slightly clayey. Sample 158. | 6 | |
| Shale, dark gray to black, fossiliferous. | 1+ | |

Another sample of similar description, but only 5 feet thick, was collected 50 yards to the southeast. Sample 159.

## CHEMICAL SYMBOLS OF ELEMENTS

Chemical symbols are used in the following tables to designate the trace elements mentioned. The symbols and the elements they represent are indicated below.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| B | Boron | Cu | Copper | Mn | Manganese | Ni | Nickel | Ti | Titanium |
| Ba | Barium | Fe | Iron | Mo | Molybdenum | Pb | Lead | V | Vanadium |
| Cr | Chromium | K | Potassium | Na | Sodium | Sr | Strontium | Zn | Zinc |

Other symbols used in the tables are tr for trace and nd for not detected.

Table 1. - Results of Spectrographic

| Samp. No. | Formation | See p. | B | Ba | Cr | Cu | Fe | K | Mn | Mo |
|---|---|---|---|---|---|---|---|---|---|---|
| 101 | Pontiac | 17 | 0.001 | 0.06 | 0.0009 | 0.001 | 1.0 | 0.14 | 0.16 | 0.0002 |
| 103 | Pontiac | 17 | 0.0004 | 0.007 | nd | 0.0007 | 1.0 | 0.03 | 0.20 | nd |
| 104 | Pontiac | 17 | 0.0004 | 0.002 | 0.0003 | 0.002 | 1.3 | 0.03 | 0.20 | nd |
| 105 | Pontiac | 17 | 0.0005 | 0.002 | 0.0003 | 0.001 | 0.66 | 0.05 | 0.14 | 0.0002 |
| 106 | Millersville | 16 | 0.0003 | 0.0016 | nd | 0.0007 | 0.67 | 0.03 | 0.04 | nd |
| 107 | Millersville | 16 | 0.0004 | 0.0018 | nd | 0.0007 | 0.61 | 0.04 | 0.04 | 0.0002 |
| 109 | Millersville | 16 | 0.0005 | 0.0019 | 0.0004 | 0.001 | 0.38 | 0.06 | 0.05 | nd |
| 110 | Millersville | 16 | 0.003 | 0.008 | 0.0037 | 0.003 | 0.80 | 0.58 | 0.12 | nd |
| 111 | Millersville | 16 | 0.0004 | 0.0013 | 0.0004 | 0.001 | 0.34 | 0.06 | 0.05 | nd |
| 112 | Millersville | 16 | 0.004 | 0.007 | 0.0061 | 0.003 | 1.0 | 0.69 | 0.04 | nd |
| 114 | Livingston | 11 | 0.0006 | 0.016 | 0.0005 | 0.002 | 0.95 | 0.08 | 0.18 | nd |
| 116 | Livingston | 11 | 0.002 | 0.0045 | 0.0017 | 0.002 | 0.97 | 0.26 | 0.10 | nd |
| 118 | Livingston | 11 | 0.002 | 0.0032 | 0.0016 | 0.002 | 1.1 | 0.27 | 0.10 | nd |
| 119 | Livingston | 11 | 0.0009 | 1.0 | 0.0006 | 0.003 | 1.7 | 0.10 | 0.18 | nd |
| 122 | Livingston | 10 | 0.0003 | 0.001 | 0.0012 | 0.001 | 0.37 | 0.04 | 0.12 | nd |
| 124 | Livingston | 10 | 0.0005 | 0.003 | 0.0003 | 0.001 | 0.57 | 0.06 | 0.14 | nd |
| 126 | Livingston | 10 | 0.001 | 0.015 | 0.0009 | 0.001 | 1.0 | 0.14 | 0.10 | nd |
| 127 | Livingston | 10 | 0.0003 | 0.001 | 0.0003 | 0.001 | 0.41 | 0.04 | 0.11 | nd |
| 129 | Livingston | 10 | 0.002 | 0.011 | 0.0007 | 0.001 | 0.54 | 0.14 | 0.11 | nd |
| 132 | Shoal Creek | 18 | 0.002 | 0.0056 | 0.0011 | 0.002 | 2.2 | 0.16 | 0.21 | nd |
| 133 | Shoal Creek | 18 | 0.002 | 0.0033 | 0.0011 | 0.002 | 2.2 | 0.19 | 0.22 | nd |
| 135 | Shoal Creek | 17 | 0.002 | 0.006 | 0.0011 | 0.002 | 2.0 | 0.21 | 0.20 | nd |
| 138 | Shoal Creek | 10 | 0.004 | 0.004 | 0.0022 | 0.002 | 1.9 | 0.39 | 0.14 | nd |
| 139 | Shoal Creek | 10 | 0.002 | 0.004 | 0.0017 | 0.002 | 2.5 | 0.23 | 0.19 | nd |
| 141 | Shoal Creek | 10 | 0.02 | 0.0055 | 0.0009 | 0.002 | 1.3 | 0.16 | 0.15 | nd |
| 142 | Shoal Creek | 10 | 0.003 | 0.005 | 0.0022 | 0.002 | 2.2 | 0.23 | 0.16 | nd |
| 144 | Shoal Creek | 11 | 0.004 | 0.005 | 0.0025 | 0.003 | 4.6 | 0.16 | 0.37 | 0.001 |
| 146 | Shoal Creek | 11 | 0.001 | 0.027 | 0.0007 | 0.002 | 1.9 | 0.09 | 0.18 | nd |
| 147 | Shoal Creek | 12 | 0.001 | 0.0039 | 0.0009 | 0.001 | 1.7 | 0.19 | 0.21 | nd |
| 149 | Shoal Creek | 12 | 0.001 | 0.022 | 0.0006 | 0.002 | 1.6 | 0.10 | 0.16 | nd |
| 152 | Shoal Creek | 14 | 0.001 | 0.0021 | 0.0005 | 0.001 | 1.9 | 0.05 | 0.24 | nd |
| 153 | Shoal Creek | 14 | 0.0004 | 0.0011 | 0.0003 | 0.0008 | 1.3 | 0.04 | 0.19 | nd |
| 154 | Shoal Creek | 10 | 0.001 | 0.0020 | 0.0004 | 0.002 | 1.5 | 0.09 | 0.13 | nd |
| 155 | Shoal Creek | 10 | 0.002 | 0.0027 | 0.0007 | 0.002 | 1.9 | 0.09 | 0.15 | nd |
| 158 | Omega | 19 | 0.001 | 0.10 | 0.0004 | 0.001 | 1.1 | 0.08 | 0.17 | nd |
| 159 | Omega | 19 | 0.001 | 0.06 | 0.0004 | 0.001 | 1.3 | 0.07 | 0.17 | 0.0002 |
| 162 | Lonsdale | 18 | 0.001 | 0.0026 | 0.0004 | 0.001 | 0.71 | 0.07 | 0.07 | nd |
| 163 | Lonsdale | 18 | 0.0005 | 0.012 | 0.0007 | 0.002 | 0.97 | 0.12 | 0.08 | 0.0002 |
| 164 | Lonsdale | 12 | 0.001 | 0.0020 | 0.0005 | 0.001 | 0.75 | 0.07 | 0.08 | nd |
| 165 | Lonsdale | 13 | 0.002 | 0.0021 | 0.0008 | 0.002 | 0.99 | 0.12 | 0.09 | nd |
| 168 | Lonsdale | 13 | 0.0006 | 0.0023 | 0.0005 | 0.002 | 1.6 | 0.10 | 0.13 | nd |
| 169 | Lonsdale | 12 | 0.002 | 0.0025 | 0.0008 | 0.002 | 2.2 | 0.10 | 0.17 | nd |
| 171 | Lonsdale | 19 | 0.002 | 0.009 | 0.0024 | 0.003 | 1.1 | 0.61 | 0.05 | 0.002 |
| 172 | Lonsdale | 19 | 0.002 | 0.0015 | 0.0012 | 0.002 | 1.4 | 0.20 | 0.12 | nd |
| 174 | Lonsdale | 11 | 0.001 | 0.012 | 0.0009 | 0.001 | 1.2 | 0.11 | 0.21 | nd |

Analyses of Limestone Samples

| Samp. No. | Formation | See p. | Na | Ni | Pb | Sr | Ti | V | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 101 | Pontiac | 17 | 0.09 | 0.001 | 0.002 | 0.035 | 0.05 | | 0.01 |
| 103 | Pontiac | 17 | 0.04 | nd | 0.001 | 0.032 | tr | | nd |
| 104 | Pontiac | 17 | 0.03 | nd | 0.001 | 0.024 | tr | | nd |
| 105 | Pontiac | 17 | 0.04 | nd | 0.001 | 0.027 | tr | | nd |
| 106 | Millersville | 16 | tr | nd | 0.0006 | 0.054 | tr | | nd |
| 107 | Millersville | 16 | 0.03 | nd | 0.0007 | 0.052 | tr | | nd |
| 109 | Millersville | 16 | 0.03 | 0.001 | 0.002 | 0.048 | tr | | nd |
| 110 | Millersville | 16 | 0.12 | 0.004 | 0.004 | 0.046 | 0.14 | tr | 0.02 |
| 111 | Millersville | 16 | tr | 0.001 | 0.0006 | 0.052 | tr | | nd |
| 112 | Millersville | 16 | 0.21 | 0.005 | 0.007 | 0.052 | 0.24 | tr | 0.02 |
| 114 | Livingston | 11 | 0.04 | 0.001 | 0.002 | 0.037 | tr | | 0.01 |
| 116 | Livingston | 11 | 0.07 | 0.002 | 0.002 | 0.058 | 0.07 | | nd |
| 118 | Livingston | 11 | 0.07 | 0.002 | 0.002 | 0.058 | 0.07 | | nd |
| 119 | Livingston | 11 | 0.04 | 0.002 | 0.005 | 0.044 | 0.04 | | 0.01 |
| 122 | Livingston | 10 | tr | nd | 0.002 | 0.030 | tr | | nd |
| 124 | Livingston | 10 | 0.03 | nd | 0.001 | 0.035 | tr | | 0.005 |
| 126 | Livingston | 10 | 0.03 | 0.001 | 0.002 | 0.055 | 0.04 | | 0.005 |
| 127 | Livingston | 10 | tr | nd | 0.001 | 0.035 | tr | | 0.005 |
| 129 | Livingston | 10 | 0.03 | 0.001 | 0.002 | 0.050 | 0.03 | | 0.005 |
| 132 | Shoal Creek | 18 | 0.07 | 0.004 | 0.007 | 0.048 | 0.06 | | nd |
| 133 | Shoal Creek | 18 | 0.06 | 0.003 | 0.006 | 0.044 | 0.04 | | nd |
| 135 | Shoal Creek | 17 | 0.07 | 0.003 | 0.003 | 0.052 | 0.05 | | nd |
| 138 | Shoal Creek | 10 | 0.12 | 0.002 | 0.002 | 0.067 | 0.09 | | nd |
| 139 | Shoal Creek | 10 | 0.09 | 0.003 | 0.01 | 0.052 | 0.08 | | nd |
| 141 | Shoal Creek | 10 | 0.07 | 0.002 | 0.002 | 0.050 | 0.04 | | nd |
| 142 | Shoal Creek | 10 | 0.14 | 0.002 | 0.003 | 0.062 | 0.11 | | 0.02 |
| 144 | Shoal Creek | 11 | 0.18 | 0.003 | 0.005 | 0.053 | 0.15 | | 0.02 |
| 146 | Shoal Creek | 11 | 0.04 | 0.002 | 0.002 | 0.054 | 0.03 | | nd |
| 147 | Shoal Creek | 12 | 0.05 | 0.002 | 0.01 | 0.073 | 0.05 | | 0.03 |
| 149 | Shoal Creek | 12 | 0.04 | 0.002 | 0.005 | 0.046 | 0.03 | | nd |
| 152 | Shoal Creek | 14 | 0.03 | 0.001 | 0.001 | 0.052 | tr | | nd |
| 153 | Shoal Creek | 14 | 0.03 | nd | 0.0008 | 0.056 | tr | | nd |
| 154 | Shoal Creek | 10 | 0.03 | 0.001 | 0.002 | 0.040 | tr | | nd |
| 155 | Shoal Creek | 10 | 0.04 | 0.002 | 0.004 | 0.047 | 0.03 | | nd |
| 158 | Omega | 19 | 0.04 | 0.001 | 0.002 | 0.066 | tr | | 0.005 |
| 159 | Omega | 19 | 0.04 | 0.001 | 0.002 | 0.067 | tr | | nd |
| 162 | Lonsdale | 18 | 0.04 | 0.001 | 0.002 | 0.061 | tr | | nd |
| 163 | Lonsdale | 18 | 0.05 | 0.002 | 0.003 | 0.059 | 0.03 | | nd |
| 164 | Lonsdale | 12 | 0.04 | 0.001 | 0.002 | 0.060 | tr | | 0.01 |
| 165 | Lonsdale | 13 | 0.05 | 0.002 | 0.004 | 0.055 | 0.04 | | 0.02 |
| 168 | Lonsdale | 13 | 0.03 | 0.001 | 0.003 | 0.047 | tr | | 0.02 |
| 169 | Lonsdale | 12 | 0.04 | 0.002 | 0.004 | 0.044 | 0.04 | | 0.01 |
| 171 | Lonsdale | 19 | 0.16 | 0.003 | 0.002 | 0.046 | 0.11 | | nd |
| 172 | Lonsdale | 19 | 0.07 | 0.001 | 0.003 | 0.050 | 0.06 | | nd |
| 174 | Lonsdale | 11 | 0.03 | 0.002 | 0.003 | 0.037 | 0.03 | | nd |

Table 1. -

| Samp. No. | Formation | See p. | B | Ba | Cr | Cu | Fe | K | Mn | Mo |
|---|---|---|---|---|---|---|---|---|---|---|
| 175 | Lonsdale | 11 | 0.001 | 0.042 | 0.0009 | 0.002 | 1.9 | 0.09 | 0.22 | nd |
| 177 | Seville | 12 | 0.002 | 0.008 | 0.0042 | 0.004 | 1.2 | 0.33 | 0.06 | 0.0002 |
| 179 | Lonsdale | 15 | 0.002 | 0.009 | 0.0018 | 0.002 | 0.77 | 0.31 | 0.06 | 0.0002 |
| 180 | Lonsdale | 15 | 0.002 | 0.008 | 0.0019 | 0.002 | 0.72 | 0.39 | 0.04 | 0.001 |
| 182 | Lonsdale | 17 | 0.0004 | 0.13 | 0.0033 | 0.002 | 0.75 | 0.27 | 0.18 | nd |
| 183 | Lonsdale | 17 | 0.001 | 0.008 | 0.0016 | 0.002 | 1.0 | 0.27 | 0.07 | nd |
| 185 | Lonsdale | 13 | 0.001 | 0.006 | 0.0013 | 0.001 | 0.54 | 0.22 | 0.07 | nd |
| 186 | Lonsdale | 13 | 0.002 | 0.020 | 0.0007 | 0.002 | 0.50 | 0.20 | 0.10 | 0.0002 |
| 188 | Lonsdale | 13 | 0.003 | 0.004 | 0.0023 | 0.001 | 0.61 | 0.27 | 0.09 | nd |
| 190 | Pontiac | 11 | 0.0004 | 0.0018 | 0.0007 | 0.002 | 0.64 | 0.13 | 0.14 | nd |
| 191 | Pontiac | 11 | 0.002 | 0.0018 | 0.0008 | 0.001 | 0.69 | 0.15 | 0.12 | nd |
| 193 | Pontiac | 19 | 0.003 | 0.0027 | 0.0008 | 0.001 | 0.62 | 0.14 | 0.09 | nd |
| 194 | Pontiac | 19 | 0.002 | 0.0029 | 0.0010 | 0.001 | 0.67 | 0.21 | 0.14 | nd |
| 196 | Pontiac | 16 | 0.003 | 0.0029 | 0.0007 | 0.002 | 0.67 | 0.17 | 0.12 | nd |
| 197 | Pontiac | 16 | 0.002 | 0.0023 | 0.0010 | 0.002 | 0.48 | 0.17 | 0.10 | 0.0003 |
| 199 | Pontiac | 14 | 0.0005 | 0.0014 | 0.0006 | 0.001 | 0.68 | 0.06 | 0.16 | nd |
| 200 | Pontiac | 14 | 0.0006 | 0.0031 | 0.0006 | 0.001 | 0.85 | 0.05 | 0.18 | nd |
| 202 | Omega | 13 | 0.001 | 0.009 | 0.0014 | 0.003 | 2.2 | 0.21 | 0.12 | 0.0006 |
| 203 | Omega | 13 | 0.002 | 0.008 | 0.0020 | 0.003 | 1.5 | 0.30 | 0.09 | 0.002 |
| 206 | Livingston | 15 | 0.0003 | 0.038 | 0.0004 | 0.001 | 0.69 | 0.04 | 0.12 | nd |
| 208 | Livingston | 15 | 0.0007 | 0.0034 | 0.0007 | 0.001 | 0.60 | 0.10 | 0.10 | nd |
| 209 | Livingston | 16 | 0.002 | 0.02 | 0.0009 | 0.002 | 0.90 | 0.15 | 0.13 | nd |
| 211 | Livingston | 16 | 0.0008 | 0.24 | 0.0006 | 0.001 | 0.54 | 0.10 | 0.09 | nd |
| 213 | Livingston | 18 | 0.001 | 0.003 | 0.0007 | 0.002 | 0.98 | 0.11 | 0.11 | nd |
| 214 | Livingston | 18 | 0.001 | 0.003 | 0.0006 | 0.002 | 1.4 | 0.09 | 0.14 | nd |
| 217 | Livingston | 12 | 0.002 | 0.009 | 0.0039 | 0.006 | 1.2 | 0.55 | 0.14 | nd |
| 218 | Livingston | 12 | 0.0005 | 0.2 | 0.0003 | 0.001 | 0.90 | 0.06 | 0.17 | nd |
| 220 | Livingston | 12 | 0.005 | 0.005 | 0.0015 | 0.002 | 0.87 | 0.27 | 0.16 | nd |
| 221 | Livingston | 12 | 0.005 | 0.018 | 0.0004 | 0.001 | 0.58 | 0.04 | 0.12 | nd |
| 225 | Livingston | 14 | 0.001 | 0.0022 | 0.0006 | 0.001 | 0.60 | 0.11 | 0.15 | nd |
| 226 | Livingston | 14 | 0.0003 | 0.0018 | 0.0003 | 0.0004 | 0.57 | 0.07 | 0.15 | nd |
| 228 | Lonsdale | 9 | 0.0004 | 0.0021 | nd | 0.002 | 2.2 | 0.05 | 0.18 | nd |
| 230 | Lonsdale | 9 | 0.002 | 0.0022 | 0.0008 | 0.002 | 0.93 | 0.10 | 0.11 | nd |
| 231 | Lonsdale | 9 | 0.001 | 0.003 | 0.0008 | 0.003 | 3.9 | 0.03 | 0.19 | 0.0005 |
| 233 | Lonsdale | 9 | 0.005 | 0.002 | 0.0007 | 0.002 | 0.75 | 0.09 | 0.09 | nd |
| 235 | LaSalle | 9 | 0.001 | 0.0012 | 0.0006 | 0.001 | 0.55 | 0.09 | 0.19 | nd |
| 236 | LaSalle | 9 | 0.002 | 0.0024 | 0.0009 | 0.001 | 0.40 | 0.17 | 0.12 | nd |
| 237 | LaSalle | 9 | 0.002 | 0.0021 | 0.0009 | 0.001 | 0.50 | 0.14 | 0.13 | nd |
| 238-240 | " | 9 | 0.003 | 0.002 | 0.0037 | 0.007 | 1.4 | 0.29 | 0.31 | nd |
| 241 | LaSalle | 9 | 0.004 | 0.007 | 0.0039 | 0.003 | 1.0 | 0.75 | 0.07 | nd |
| 242 | LaSalle | 9 | 0.005 | 0.0035 | 0.0014 | 0.001 | 0.50 | 0.21 | 0.09 | nd |
| 244 | LaSalle | 15 | 0.001 | 0.0015 | 0.0012 | 0.002 | 1.1 | 0.12 | 0.22 | nd |
| 246 | LaSalle | 15 | 0.003 | 0.002 | 0.0011 | 0.005 | 0.51 | 0.22 | 0.09 | nd |
| 256 | Millersville | 18 | 0.0006 | 0.0012 | 0.003 | 0.0007 | 0.32 | 0.06 | 0.04 | nd |
| 260 | LaSalle | 14 | 0.005 | 0.0024 | 0.0008 | 0.001 | 0.43 | 0.13 | 0.11 | nd |
| 264 | Livingston | 15 | 0.0001 | 0.0011 | 0.0003 | 0.001 | 0.48 | 0.05 | 0.11 | nd |

Continued

| Samp. No. | Formation | See p. | Na | Ni | Pb | Sr | Ti | V | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 175 | Lonsdale | 11 | 0.03 | 0.002 | 0.003 | 0.044 | 0.05 | | nd |
| 177 | Seville | 12 | 0.08 | 0.005 | 0.008 | 0.021 | 0.06 | | nd |
| 179 | Lonsdale | 15 | 0.12 | 0.002 | 0.002 | 0.036 | 0.07 | | nd |
| 180 | Lonsdale | 15 | 0.12 | 0.002 | 0.004 | 0.042 | 0.08 | | nd |
| 182 | Lonsdale | 17 | 0.09 | 0.001 | 0.003 | 0.039 | 0.06 | | nd |
| 183 | Lonsdale | 17 | 0.08 | 0.003 | 0.003 | 0.035 | 0.06 | | nd |
| 185 | Lonsdale | 13 | 0.06 | nd | 0.002 | 0.044 | 0.06 | | nd |
| 186 | Lonsdale | 13 | 0.06 | 0.002 | 0.003 | 0.056 | 0.06 | | 0.005 |
| 188 | Lonsdale | 13 | 0.08 | nd | 0.004 | 0.044 | 0.06 | | nd |
| 190 | Pontiac | 11 | 0.06 | 0.001 | 0.002 | 0.055 | 0.04 | | nd |
| 191 | Pontiac | 11 | 0.07 | 0.001 | 0.003 | 0.049 | 0.04 | | nd |
| 193 | Pontiac | 19 | 0.07 | 0.001 | 0.002 | 0.054 | 0.03 | | 0.01 |
| 194 | Pontiac | 19 | 0.09 | 0.001 | 0.003 | 0.060 | 0.05 | | 0.01 |
| 196 | Pontiac | 16 | 0.08 | 0.001 | 0.003 | 0.054 | 0.05 | | nd |
| 197 | Pontiac | 16 | 0.08 | nd | 0.002 | 0.064 | 0.05 | | nd |
| 199 | Pontiac | 14 | 0.04 | nd | 0.001 | 0.042 | tr | | 0.005 |
| 200 | Pontiac | 14 | 0.04 | nd | 0.002 | 0.036 | tr | | 0.01 |
| 202 | Omega | 13 | 0.10 | 0.002 | 0.003 | 0.053 | 0.06 | | nd |
| 203 | Omega | 13 | 0.14 | 0.003 | 0.004 | 0.050 | 0.08 | | 0.01 |
| 206 | Livingston | 15 | tr | 0.001 | 0.001 | 0.031 | tr | | 0.005 |
| 208 | Livingston | 15 | 0.03 | 0.001 | 0.001 | 0.054 | tr | | nd |
| 209 | Livingston | 16 | 0.05 | 0.002 | 0.002 | 0.030 | 0.04 | | 0.01 |
| 211 | Livingston | 16 | 0.03 | 0.001 | 0.001 | 0.055 | tr | | nd |
| 213 | Livingston | 18 | 0.03 | 0.002 | 0.003 | 0.039 | tr | | nd |
| 214 | Livingston | 18 | 0.04 | 0.002 | 0.002 | 0.038 | tr | | nd |
| 217 | Livingston | 12 | 0.20 | 0.005 | 0.004 | 0.048 | 0.14 | | 0.01 |
| 218 | Livingston | 12 | 0.04 | 0.001 | 0.001 | 0.044 | tr | | nd |
| 220 | Livingston | 12 | 0.08 | 0.002 | 0.003 | 0.052 | 0.06 | | 0.01 |
| 221 | Livingston | 12 | 0.03 | 0.007 | 0.0008 | 0.040 | tr | | 0.02 |
| 225 | Livingston | 14 | 0.06 | 0.001 | 0.001 | 0.050 | tr | | nd |
| 226 | Livingston | 14 | 0.04 | nd | 0.0006 | 0.053 | tr | | nd |
| 228 | Lonsdale | 9 | 0.03 | 0.001 | 0.002 | 0.044 | tr | | 0.07 |
| 230 | Lonsdale | 9 | 0.05 | 0.002 | 0.003 | 0.052 | 0.04 | | 0.01 |
| 231 | Lonsdale | 9 | 0.04 | 0.003 | 0.004 | 0.053 | 0.04 | | nd |
| 233 | Lonsdale | 9 | 0.05 | 0.002 | 0.001 | 0.058 | 0.03 | | 0.01 |
| 235 | LaSalle | 9 | 0.06 | 0.001 | 0.003 | 0.044 | 0.04 | | nd |
| 236 | LaSalle | 9 | 0.08 | 0.001 | 0.002 | 0.056 | 0.05 | | nd |
| 237 | LaSalle | 9 | 0.06 | 0.001 | 0.002 | 0.039 | 0.03 | | nd |
| 238-240 | " | 9 | 0.12 | 0.001 | 0.004 | 0.053 | 0.07 | | nd |
| 241 | LaSalle | 9 | 0.33 | 0.004 | 0.002 | 0.081 | 0.16 | tr | nd |
| 242 | LaSalle | 9 | 0.09 | 0.002 | 0.003 | 0.050 | 0.06 | | nd |
| 244 | LaSalle | 15 | 0.08 | 0.002 | 0.006 | 0.040 | 0.05 | | nd |
| 246 | LaSalle | 15 | 0.08 | 0.002 | 0.002 | 0.041 | 0.05 | | nd |
| 256 | Millersville | 18 | 0.03 | nd | 0.0008 | 0.046 | tr | | nd |
| 260 | LaSalle | 14 | 0.06 | 0.002 | 0.003 | 0.036 | 0.04 | | nd |
| 264 | Livingston | 15 | 0.03 | nd | 0.0005 | 0.038 | tr | nd | nd |

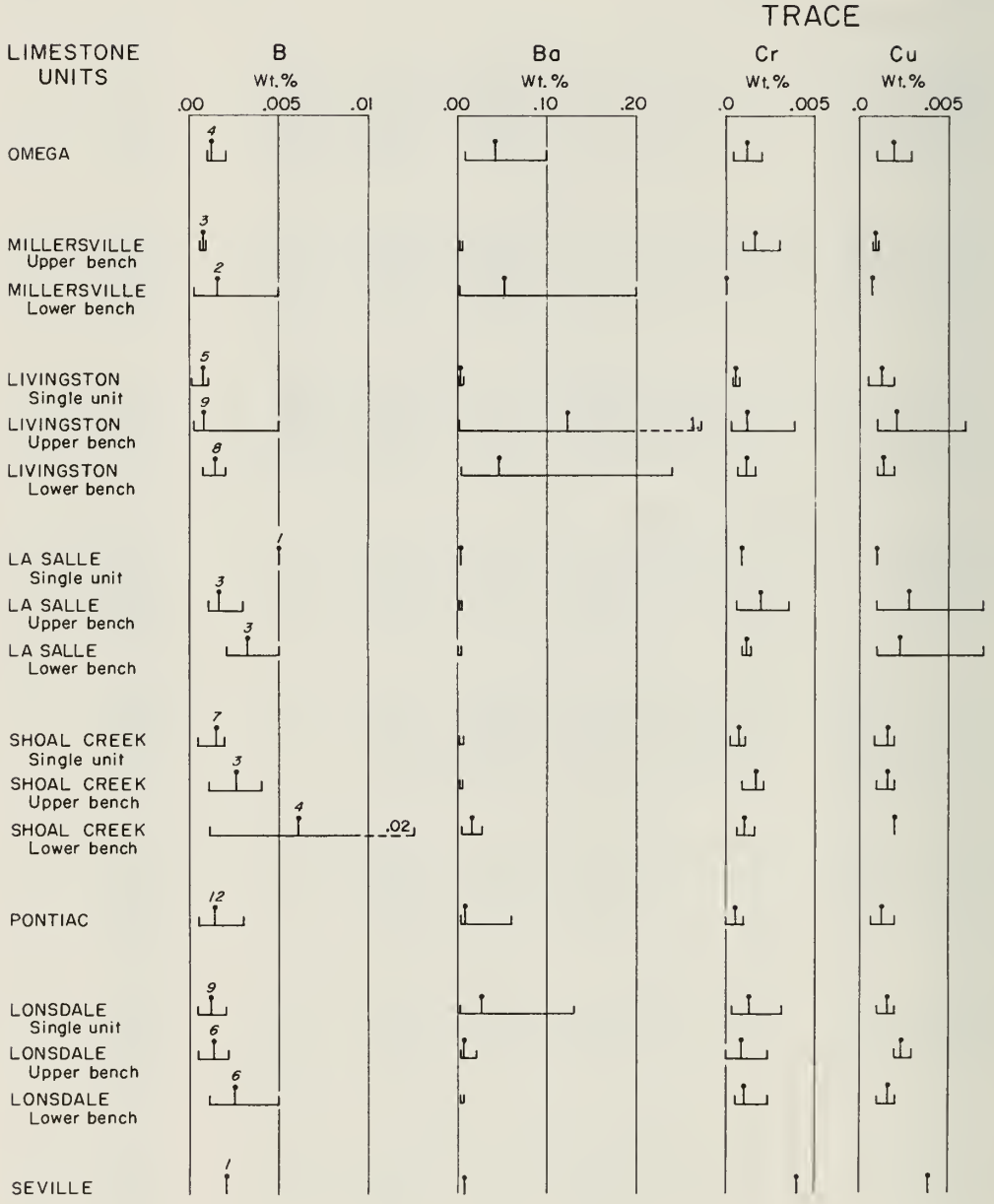
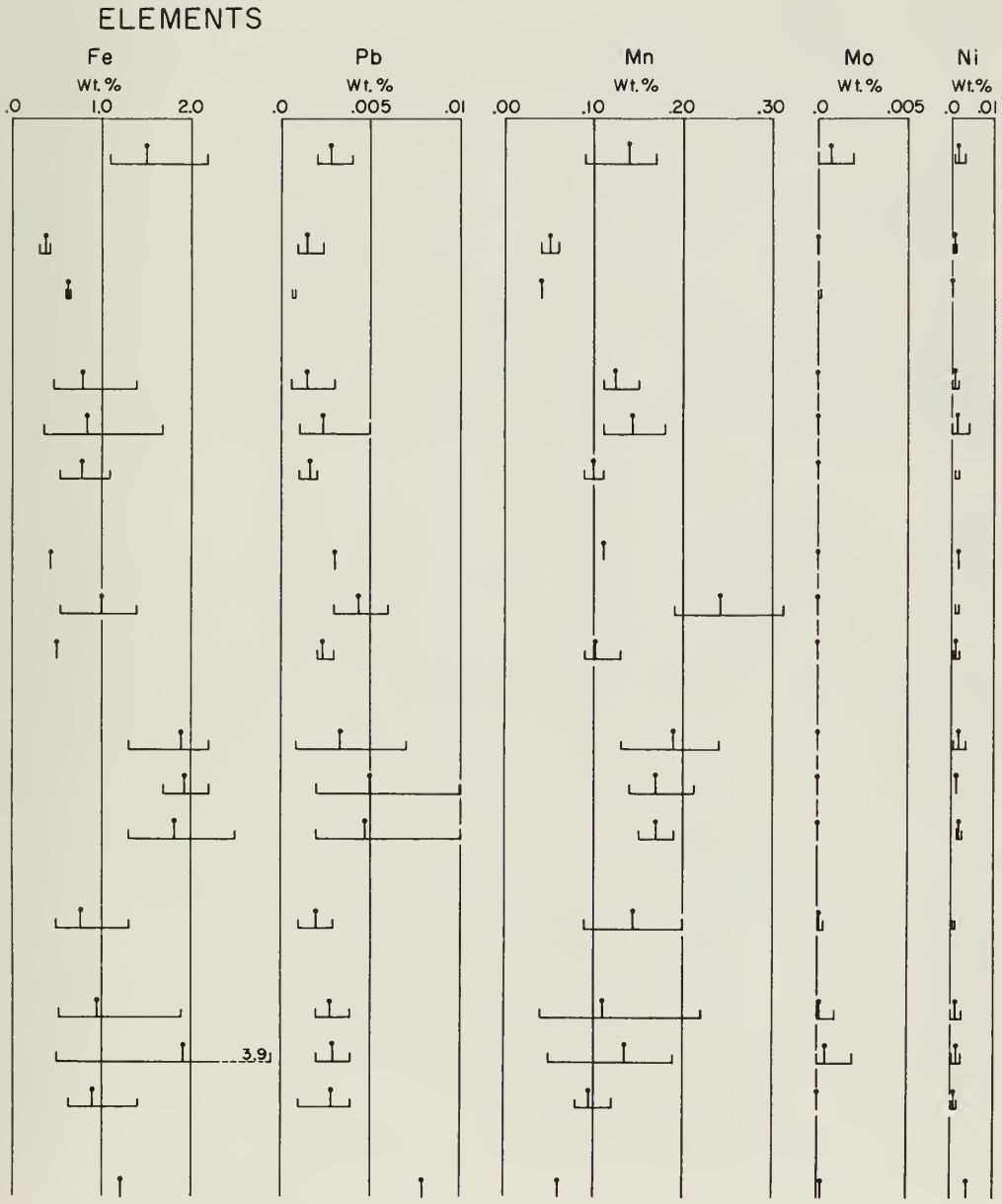



Fig. 3. - Average percentage and range in quantity of trace element content
the dots the average percentage. Numbers above the averages in the column




of limestone units. The length of the horizontal bars indicates the range and for boron (B) indicate the number of samples collected from each unit.

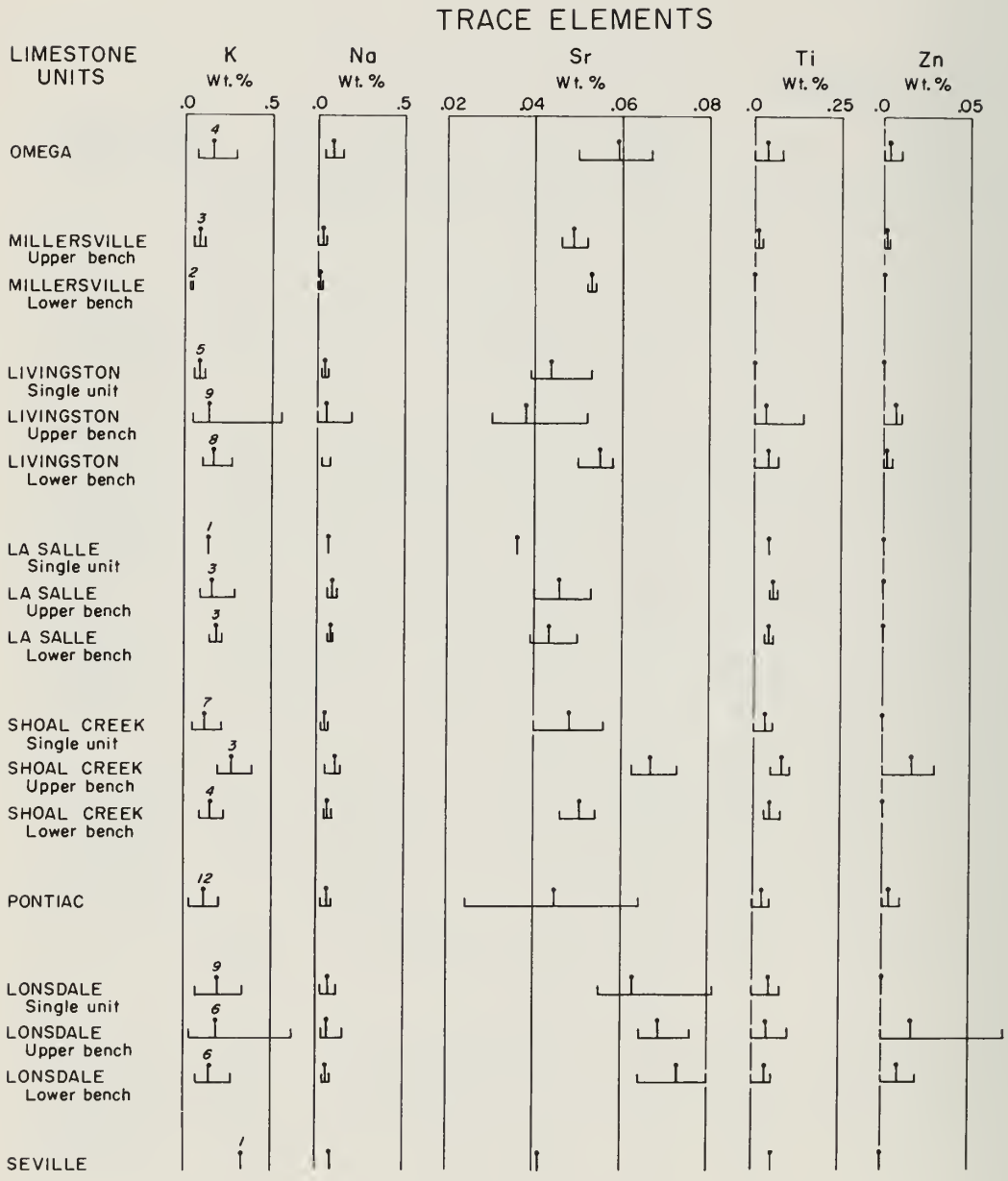



Fig. 3 (cont'd). - Average percentage and range in quantity of trace element content of limestone units. The length of the horizontal bars indicates the range and the dots the average percentage. Numbers above the averages in the column for potassium (K) indicate the number of samples collected from each unit.

## KINDS AND AMOUNTS OF TRACE ELEMENTS

Data on those trace elements of possible significance to agriculture, and on barium, nickel, lead, strontium, and vanadium, are given in table 1. These are the principal trace elements noted in the samples using the methods and limits of detection previously described. No cobalt was detected in any of the samples.

Table 3 shows the range and average content of each element. It involves 17 samples of shale and 88 samples of limestone from quarry faces.

The average content of barium, manganese, and strontium, and the average range of barium and manganese in the limestone samples, are higher than the averages and ranges of these elements in the shale samples. This suggests that these elements commonly are more closely associated with the minerals composing limestone than those of the shales. The average amounts and ranges of amounts of the other 12 trace elements investigated are highest in the shales.

The limestones have the lowest range in amounts of all trace elements except manganese. It is evident that agricultural limestone made from clayey limestone or from deposits that contain clay or shale will receive contributions of trace elements from the clay or shale. Clay or shale overburden unavoidably included with the quarry stone also may contribute trace elements.

## AVERAGE AND RANGE OF TRACE ELEMENT CONTENT

The range in the quantity of each trace element in the various limestone units sampled is shown graphically in figure 3, as is the average percentage of each trace element in each limestone unit. Table 4 indicates which limestone unit has the highest average amount and which the lowest average amount of a given trace element. Also shown are those limestone units having the widest and narrowest ranges in amounts of the various trace elements. In case the averages or ranges of two or more of the limestone units are nearly the same, all such occurrences are recorded in the table.

Data similar to the above for the shales sampled are given in figure 4 and table 5.

Of the limestone units (table 4), the upper bench of the Shoal Creek has the highest average content of five trace elements - iron, potassium, sodium, lead, and titanium. The upper bench of the LaSalle contains the highest average content of three trace elements - chromium, copper, and manganese. The Livingston upper bench shows the widest ranges for five trace elements. Four trace elements have their widest range in the upper Lonsdale.

The lower bench of the Millersville limestone has the lowest average content for the nine trace elements chromium, copper, potassium, manganese, sodium, nickel, lead, titanium, and zinc, followed by the single bench Livingston, which has the lowest average content for the four trace elements boron, molybdenum, titanium, and zinc. The narrowest ranges of trace element content are in the lower unit of the Millersville limestone (10 elements) and the lower bench of the LaSalle (four elements).

Table 5 shows that the shale units of the Shoal Creek contain the highest average amounts of ten trace elements. The shales of the LaSalle and Livingston contain the highest average amounts of two trace elements and the Lonsdale shale is highest in one. Ten elements show their widest range in the Livingston shale. The shales of the Lonsdale and LaSalle have the lowest average content of seven and six elements, respectively. The LaSalle has the narrowest range of content for eight elements and is followed closely by the Shoal Creek with five.

Table 2. - Results of Spectrographic

| Samp. No. | Formation | See p. | B | Ba | Cr | Cu | Fe | K | Mn | Mo |
|---|---|---|---|---|---|---|---|---|---|---|
| 115 | Livingston | 11 | 0.009 | 0.022 | 0.012 | 0.008 | 1.6 | 1.8 | tr | nd |
| 120 | Livingston | 11 | 0.02 | 0.013 | 0.015 | 0.01 | 2.0 | 2.2 | tr | nd |
| 123 | Livingston | 10 | 0.01 | 0.02 | 0.014 | 0.01 | 3.0 | 1.8 | 0.03 | nd |
| 125 | Livingston | 10 | 0.03 | 0.021 | 0.015 | 0.01 | 2.7 | 1.8 | 0.02 | nd |
| 128 | Livingston | 10 | 0.02 | 0.02 | 0.018 | 0.01 | 2.6 | 1.9 | 0.02 | nd |
| 140 | Shoal Creek | 10 | 0.02 | 0.03 | 0.014 | 0.01 | 4.7 | 2.2 | 0.03 | 0.0004 |
| 145 | Shoal Creek | 11 | 0.02 | 0.02 | 0.012 | 0.01 | 5.3 | 1.8 | 0.06 | 0.001 |
| 148 | Shoal Creek | 12 | 0.02 | 0.03 | 0.012 | 0.02 | 5.2 | 1.9 | 0.04 | 0.001 |
| 166 | Lonsdale | 13 | 0.01 | 0.01 | 0.009 | 0.01 | 2.2 | 1.5 | 0.03 | 0.0005 |
| 167 | Lonsdale | 12 | 0.01 | 0.018 | 0.008 | 0.01 | 2.4 | 1.7 | 0.02 | 0.0005 |
| 187 | Lonsdale | 13 | 0.004 | 0.012 | 0.0046 | 0.006 | 1.3 | 1.0 | 0.02 | 0.006 |
| 207 | Livingston | 15 | 0.01 | 0.02 | 0.014 | 0.009 | 4.0 | 1.6 | 0.04 | 0.0004 |
| 210 | Livingston | 16 | 0.008 | 0.04 | 0.011 | 0.008 | 6.0 | 1.0 | 0.06 | 0.0004 |
| 229 | Lonsdale | 9 | 0.007 | 0.02 | 0.009 | 0.007 | 2.4 | 1.7 | 0.02 | 0.0004 |
| 232 | Lonsdale | 9 | 0.01 | 0.02 | 0.010 | 0.007 | 2.3 | 1.9 | 0.02 | 0.0004 |
| 245 | LaSalle | 15 | 0.007 | 0.012 | 0.0056 | 0.01 | 2.2 | 1.3 | 0.06 | 0.002 |
| 247 | LaSalle | 15 | 0.01 | 0.016 | 0.009 | 0.006 | 2.6 | 1.7 | 0.06 | nd |

## PRINCIPAL TRACE ELEMENT CHARACTERISTICS OF LIMESTONES

The number of limestone samples taken is too small and the distribution of the quarries from which they came too restricted to justify any firm conclusions regarding the principal trace element characteristics of the limestones studied. A further complexity is the fact that most of the limestones are a single bench at some places and at others consist of an upper and lower bench, generally separated by shale. Only rarely is it known with certainty whether a single unit is equivalent to the upper bench, to the lower bench, or to both benches together.

Attempts were made to correlate the various limestone units, and the shales as well, by comparing curves recording their trace element composition. This was unsuccessful, as were efforts to determine unit characteristics by means of data based on ratios between the various amounts of the different trace elements.

The following principal trace element characteristics of the limestones studied are derived from the analytical data reported above. They are subject to the limitations mentioned above. All statements relate to the average content of the element discussed in the units mentioned and the terms high and low are used comparatively.

Analyses of Shale Samples

| Samp. No. | Formation | See p. | Na | Ni | Pb | Sr | Ti | V | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 115 | Livingston | 11 | 0.39 | 0.01 | 0.01 | 0.012 | 0.53 | 0.011 | 0.01 |
| 120 | Livingston | 11 | 0.47 | 0.007 | 0.02 | 0.14 | 0.57 | 0.011 | 0.01 |
| 123 | Livingston | 10 | 0.33 | 0.010 | 0.01 | 0.02 | 0.70 | 0.011 | 0.02 |
| 125 | Livingston | 10 | 0.18 | 0.010 | 0.001 | 0.044 | 0.62 | 0.012 | 0.02 |
| 128 | Livingston | 10 | 0.18 | 0.008 | 0.02 | 0.017 | 0.75 | 0.015 | nd |
| 140 | Shoal Creek | 10 | 0.65 | 0.02 | 0.02 | 0.021 | 0.51 | 0.012 | 0.04 |
| 145 | Shoal Creek | 11 | 0.52 | 0.03 | 0.02 | 0.030 | 0.45 | 0.012 | 0.02 |
| 148 | Shoal Creek | 12 | 0.57 | 0.02 | 0.04 | 0.024 | 0.40 | 0.014 | 0.02 |
| 166 | Lonsdale | 13 | 0.45 | 0.008 | 0.01 | 0.028 | 0.43 | 0.005 | 0.02 |
| 167 | Lonsdale | 12 | 0.44 | 0.002 | 0.01 | 0.023 | 0.37 | 0.006 | 0.02 |
| 187 | Lonsdale | 13 | 0.24 | 0.005 | 0.002 | 0.084 | 0.21 | 0.004 | nd |
| 207 | Livingston | 15 | 0.32 | 0.009 | 0.01 | 0.022 | 0.37 | 0.010 | 0.02 |
| 210 | Livingston | 16 | 0.45 | 0.01 | 0.02 | 0.055 | 0.31 | 0.008 | 0.02 |
| 229 | Lonsdale | 9 | 0.47 | 0.008 | 0.01 | 0.035 | 0.50 | 0.005 | 0.02 |
| 232 | Lonsdale | 9 | 0.58 | 0.008 | 0.009 | 0.013 | 0.51 | 0.006 | 0.02 |
| 245 | LaSalle | 15 | 0.33 | 0.008 | 0.005 | 0.070 | 0.25 | 0.007 | nd |
| 247 | LaSalle | 15 | 0.77 | 0.007 | 0.02 | 0.030 | 0.32 | 0.008 | 0.005 |

Table 3. - Range and Average Percentages of Trace Elements

| Element | Limestones | | Shales | |
|---|---|---|---|---|
| | Range | Average | Range | Average |
| Boron | 0.0001 - 0.02 | 0.0018 | 0.004 - 0.03 | 0.013 |
| Barium | 0.001 - 1. | 0.0260 | 0.01 - 0.04 | 0.020 |
| Chromium | 0.0003 - 0.0061 | 0.0011 | 0.0046 - 0.018 | 0.011 |
| Copper | 0.0004 - 0.007 | 0.0018 | 0.006 - 0.02 | 0.009 |
| Iron | 0.32 - 4.6 | 1.13 | 1.3 - 6.0 | 3.1 |
| Potassium | 0.03 - 0.75 | 0.16 | 1.0 - 2.2 | 1.69 |
| Manganese | 0.04 - 0.37 | 0.14 | tr - 0.06 | 0.03 |
| Molybdenum | nd - 0.002 | 0.0001 | nd - 0.006 | 0.0008 |
| Sodium | tr - 0.33 | 0.07 | 0.18 - 0.77 | 0.43 |
| Nickel | nd - 0.007 | 0.0015 | 0.002 - 0.03 | 0.011 |
| Lead | 0.0006 - 0.01 | 0.0026 | 0.001 - 0.04 | 0.014 |
| Strontium | 0.024 - 0.081 | 0.049 | 0.012 - 0.14 | 0.039 |
| Titanium | tr - 0.24 | 0.04 | 0.21 - 0.75 | 0.46 |
| Vanadium | nd - tr | | 0.004 - 0.015 | 0.009 |
| Zinc | nd - 0.07 | 0.004 | nd - 0.04 | 0.016 |

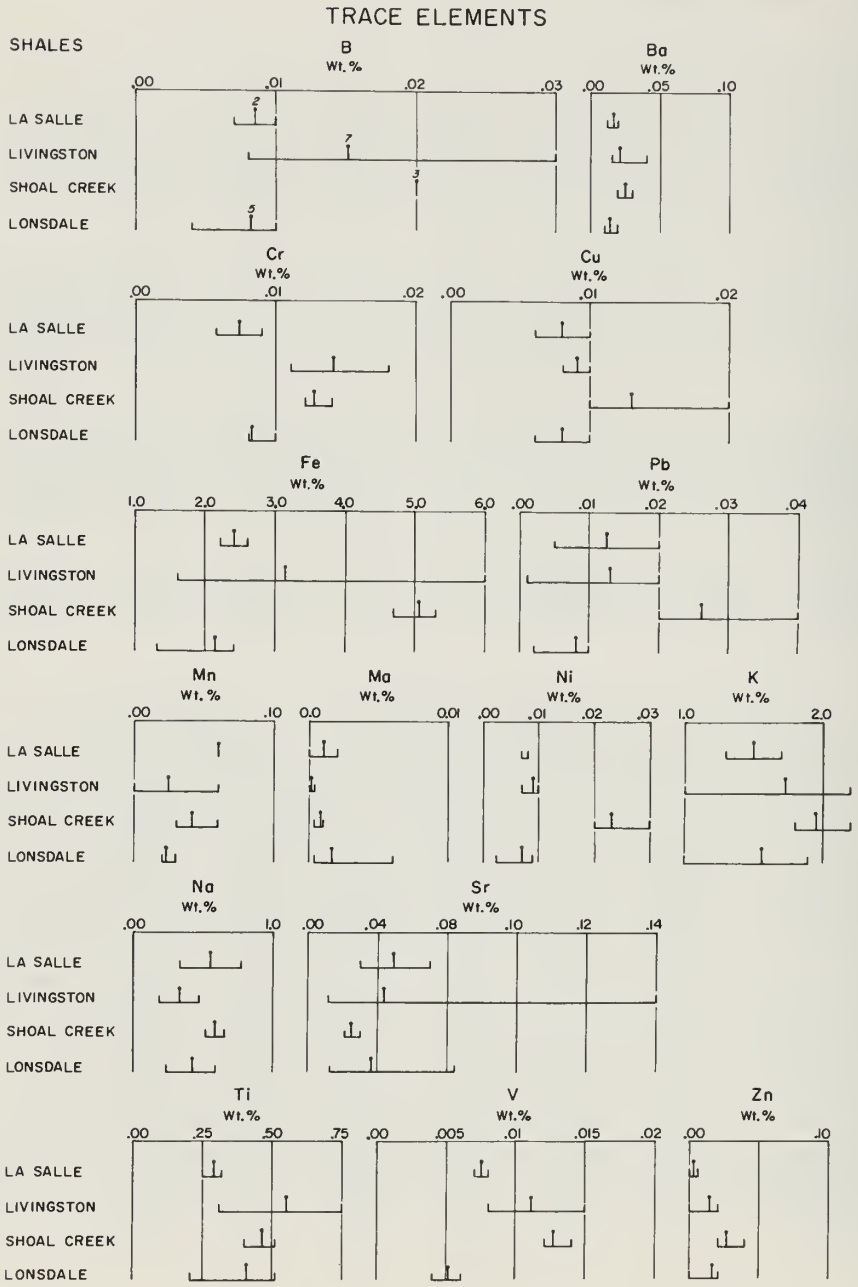



Fig. 4. - Average percentage and range in quantity of trace element content of shale units. The length of the horizontal bars indicates the range and the dots the average percentage. Numbers above the averages in the column for boron (B) indicate the number of samples collected from each unit.

Table 4. - Evaluation of Trace Element Characteristics of Limestone Units[1]

| Limestone unit and number of samples | | Occurrence of Trace Elements* | | | | | |
|---|---|---|---|---|---|---|---|
| | | Highest average amount | Lowest average amount | High average amount | Low average amount | Widest range | Narrowest range |
| Omega | 4 | Mo | | Ba Na | Mo | | |
| Millersville | | | | | | | |
| Upper U. | 3 | | Fe Mo° | Cr | Ba B Cu K Mn Ni Pb Ti Zn | | B Mo° |
| Lower U. | 2 | | Cr° Cu K Mn Na Ni° Pb Ti° Zn° | Ba | Fe Mo | | Cr° Cu K Mn Na Ni Pb Sr Ti° Zn° |
| Livingston | | | | | | | |
| Single | 5 | | B Mo° Ti° Zn° | | Ba Cr K Na Pb Sr | | Mo° Ti° Zn° |
| Upper | 9 | Ba | Mo° Sr | | B | Ba Cr Na Ni Ti | Mo° |
| Lower | 8 | | Mo° | Ba | Pb Zn | | Mo° |
| LaSalle | | | | | | | |
| Upper | 3 | Cr Cu Mn | Ba Mo° Zn° | Pb Na Ti | | Cu | Ba Mo° Zn |
| Lower | 3 | | Mo° Zn° | B Cu K | Ba Fe Cr Sr | Cu | Fe Mo° Na Zn° |
| Shoal Creek | | | | | | | |
| Single | 7 | | Mo° Zn° | Fe Mn Ni | Ba | | Mo° Zn° |
| Upper | 3 | Fe K Na Pb Ti | Mo° | B Cr Mn Sr Zn | Ba | Pb | Mo° Ni |
| Lower | 4 | B Ni | Mo° Zn° | Fe Mn Pb Ti | | B Pb | Cu Mo° Zn° |
| Pontiac | 12 | | | Mo | Cr | Sr | |
| Lonsdale | | | | | | | |
| Single | 9 | | Zn° | K Mo Ti | | Mn | Zn° |
| Upper | 6 | Zn | | Cu Fe K Mo Sr | | Fe K Mo Zn | |
| Lower | 6 | Sr | Mo° | B | Ba | | Mo° |

[1] Based on two or more samples.

* When a symbol for an element occurs more than once, this indicates that the amounts of the element were the same in all limestone units opposite which the symbol of the element appears.

° Average or range is zero.

Table 5. - Evaluation of Trace Element Characteristics of Shale Units

| Limestone unit and number of shale samples | Occurrence of trace elements* | | | |
|---|---|---|---|---|
| | Highest average amount | Lowest average amount | Widest range | Narrowest range |
| LaSalle 2 | Mn Sr | Ba Cr Cu K Ti Zn | Na | Ba Fe K Mn Ni Ti V Zn |
| Livingston 7 | Cr Ti | Mo Na | Ba B Cr Fe K Mn Sr Ti V Zn | Cu Mn Mo |
| Shoal Creek 3 | Ba B Cu Fe K Na Ni Pb V Zn | Sr | Cu Ni Pb Zn | B Cr K Na Sr |
| Lonsdale 5 | Mo | B Cu Fe Mn Ni Pb V | Mo Zn | Cr Pb |

* When the symbol for an element occurs more than once, this indicates that the amounts of the element were the same in all shales opposite which the symbol of the element appears.

BARIUM. - The upper bench of the Livingston has the highest barium content. The lower bench of the Livingston, the lower bench of the Millersville, and the Omega also are high in barium. The upper bench of the LaSalle has the lowest average barium content.

BORON. - Highest content of boron is found in the lower bench of the Shoal Creek. The lower bench of the LaSalle, upper bench of the Shoal Creek, and lower bench of the Lonsdale also are high. The boron content is lowest in the upper unit of the Millersville and the upper unit Livingston.

IRON. - High iron content appears in the upper bench of the Shoal Creek limestone. The upper bench of the Lonsdale has a high maximum range value, but its average value is no higher than several other units. Iron content also is high in the single unit Shoal Creek, lower bench of the Shoal Creek, and upper bench of the Lonsdale. The upper bench of the Millersville has the lowest average iron content.

LEAD. - Highest content of lead is found in the upper bench of the Shoal Creek limestone. The upper bench of the LaSalle and lower bench of the Shoal Creek also are high. The lower bench Millersville limestone is lowest in lead content.

MANGANESE. - The upper bench of the LaSalle limestone has the highest manganese content. It is also high in the single unit and upper bench Shoal Creek. The lower bench of the Millersville contains the least amount.

MOLYBDENUM. - Highest molybdenum content is found in the Omega limestone but it is present in about the same amount in the Pontiac and in the single unit and upper bench of the Lonsdale. Several units have zero averages of molybdenum and, therefore, the lowest average molybdenum content is not characteristic of any limestone.

POTASSIUM. - The upper bench of the Shoal Creek limestone has the highest potassium content. The lower bench of the LaSalle and the upper bench of the Lonsdale also are high in potassium. Some individual samples of other limestones also show high content. Potassium content is lowest in the lower bench of the Millersville.

STRONTIUM. - Strontium content is highest in the lower bench of the Lonsdale limestone, but also high in the upper bench of the Shoal Creek and single unit Lonsdale limestone. Strontium content is lowest in the upper bench of the Livingston limestone.

TITANIUM. - The upper bench of the Shoal Creek limestone has the highest titanium content. It also is high in the upper bench of the LaSalle, the lower bench of the Shoal Creek and the single unit Lonsdale. Titanium content is lowest in the lower bench of the Millersville and the single unit Livingston.

ZINC. - In the upper bench of the Lonsdale is found the highest zinc content, but it also is high in the upper bench of the Shoal Creek. Zinc content is zero in several units and therefore the lowest average is not characteristic of any limestone.

## PRINCIPAL TRACE ELEMENT CHARACTERISTICS OF SHALES

An evaluation of the trace element characteristics of the shales that are a part of the Pennsylvanian limestone units studied is subject to the same possible inherent sources of error as the foregoing data on limestone. The following discussion is presented, therefore, with the understanding that it carries the same limitations.

Shale beds occur in the LaSalle, Livingston, Shoal Creek, and Lonsdale limestones. The shales are listed in table 5, which gives average and range data on their trace element content, as does figure 4 graphically.

Following are the principal trace element characteristics of the shales. Unless otherwise stated, all references to the amount of trace elements refer to average values and the terms high and low are used comparatively.

BORON. - Highest boron content is in the Shoal Creek shale, though some samples of Livingston shale also are high in boron. The Lonsdale and LaSalle shales are low in boron.

BARIUM. - The Shoal Creek shale has the highest barium content, although there is very little difference among the shales. Barium content is lowest in the LaSalle shale.

CHROMIUM. - Chromium content is highest in the Livingston and lowest in the LaSalle shale, but the Shoal Creek shale is almost as high as the Livingston and the Lonsdale almost as low as the LaSalle.

COPPER. - Average and range in amounts of copper in the Shoal Creek shale is higher than all other shales. Copper content is lowest in the LaSalle and Lonsdale shales.

IRON. - Highest iron content is in the Shoal Creek, although some samples of the Livingston are higher. Iron content is lowest in the Lonsdale shale.

POTASSIUM. - The Shoal Creek has the highest potassium content and the LaSalle the lowest.

MANGANESE. - Highest manganese content is found in the LaSalle and lowest is in the Lonsdale.

MOLYBDENUM. - Average and range of molybdenum is greatest in Lonsdale and lowest in the Livingston shale.

SODIUM. - The Shoal Creek shale is highest in sodium content and Livingston shale is lowest.

NICKEL. - Highest nickel content appears in the Shoal Creek shale, lowest in the Lonsdale shale.

LEAD. - The Shoal Creek shale has the highest lead content, the Lonsdale shale the lowest.

TITANIUM. - Highest content of titanium is in the Livingston shale; lowest titanium content is in the LaSalle shale.

VANADIUM. - The Shoal Creek shale is highest in vanadium, although some samples of the Livingston shales are higher. Lowest is in the Lonsdale shale.

ZINC. - Highest zinc content is in the Shoal Creek shale, lowest in the LaSalle shale.

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